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NATURE, VALUE, AND UTILIZATION OF ALKALI LANDS,

AND

TOLERANCE OF ALKALI BY CULTURES.

By E. W. HILGARD and R. H. LOUGHRIDGE.

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NATURE, VALUE, AND UTILIZATION OF ALKALI LANDS,

AND

THE TOLERANCE OF CROPS FOR ALKALI.

By E. W. HILGARD and R. H. LOUGHRIDGE.

[The continuous and pressing demand for information on alkali lands and their utilization having exhausted the printed matter heretofore published by this Station on the subject, it seems best to publish a general summary of the results of our investigations, made during the past twenty years, for the use of farmers and land owners and the general public. Those desiring more detailed information will find the record, so far as printed, in the reports of the Station from 1879 to 1898, of which those from 1898 to 1904 are still available for distribution.]

OCCURRENCE AND CHARACTERISTICS OF ALKALI SOILS.

Alkali lands must be pointedly distinguished from the salty lands of sea margins or marshes, from which they differ in both their origin and essential nature. Marsh lands derive their salts from sea water that occasionally overflows them, and the salts which impregnate them are essentially "sea salts"; that is, common salt, together with bittern, epsom salt, etc. Very little of what would be useful to vegetation or desirable as a fertilizer is contained in the salts impregnating such soils; and they are by no means always intrinsically rich in plant-food, but vary greatly in this respect.

Alkali lands bear no definite relation to the sea; they are mostly remote from it or from any former sea bed, so that they have sometimes been designated as "terrestrial salt lands." Their existence is usually definitely traceable to climatic conditions alone. They are the natural result of a light rainfall, insufficient to leach out of the land the salts that always form in it by the progressive weathering of the rock powder of which all soils largely consist. Where the rainfall is abundant, that portion of the salts corresponding to "sea salts" is leached out into the bottom water, and with this passes through springs and rivulets into the country drainage, to be finally carried to the ocean. Another portion of the salts formed by weathering, however, is partially or wholly retained by the soil; it is that portion chiefly useful as plant-food.

It follows that when, in consequence of insufficient rainfall, all or most of the salts are retained in the soil, they will contain not only

the ingredients of sea water, but also those useful to plants. In rainy climates a large portion even of the latter is leached out and carried away. In extremely arid climates their entire mass remains in the soils; and, being largely soluble in water, evaporation during the dry season brings them to the surface, where they may accumulate to such an extent as to render the growth of ordinary useful vegetation impossible; as is seen in "alkali spots," and sometimes in extensive tracts of "alkali desert."

In looking over a rainfall map of the globe we see that a very considerable portion of the earth's surface has deficient rainfall, the latter term being commonly meant to imply any annual average less than 20 inches (500 millimeters). Zones of deficient rainfall intervene between the tropics and the temperate humid zones on both the northern and southern hemispheres, their width ranging respectively from 30 to 12 degrees, or from 2,000 to 800 miles. The arid region thus defined includes, in North America, most of the country lying west of the one hundredth meridian up to the Cascade mountains, and northward beyond the line of the United States; southward, it reaches far into Mexico, including especially the Mexican plateau. In South America it includes nearly all the Pacific slope (Peru and Chile) south to Araucania; and eastward of the Andes, the greater portion of the plains of western Brazil and Argentina. In Europe only a very small portion of the Mediterranean border is included; but the entire African coast belt opposite, with the Saharan and Libyan deserts, Egypt and Arabia are included therein, as well as a considerable portion of South Africa. In Asia, Asia Minor, Syria (with Palestine), Mesopotamia, Persia, and northwestern India up to the Ganges, and northward, the great plains or steppes of central Asia eastward to Mongolia and western China, fall into the same category; as does also a large portion of the Australian continent.

Over these vast areas alkali lands occur to a greater or less extent, the exceptions being the mountain regions and adjacent lands on the side exposed to prevailing oceanic winds. It will therefore be seen that the problem of the utilization of alkali lands for agriculture is not of local interest only, but is of world-wide importance. It will also be noted that many of the countries referred to are those in which the most ancient civilizations have existed in the past, but which at present, with few exceptions, are occupied by semicivilized people only. It is doubtless from this cause that the nature of alkali lands has until now been so little understood that even their essential distinctness from the sea-border lands has been but lately recognized in full. Moreover, the great intrinsic fertility of these lands has been very little appreciated, their repellent aspect causing them to be generally considered as waste lands.

This aspect is essentially due to their natural vegetation being in most cases confined to plants useless to man, commonly designated as "saline vegetation," of which but little is usually relished by cattle. Exceptions to this rule occur in America, Australia, and Africa, where the "saltbushes" of the former two, and the "karroo" vegetation of the latter, form valuable pasture grounds. Apart from these, however, the efforts to find for these lands, while in their natural condition, culture plants generally acceptable, or at least profitable, outside of forage crops, have not been very successful.

HOW PLANTS ARE INJURED BY ALKALI.

When we examine plants that have been injured by alkali, we will usually find that the damage has been done near the base of the trunk, or root crown; rarely at any considerable depth in the soil itself. In the case of green herbaceous stems, the bark is found to have turned to a brownish tinge for half an inch or more, so as to be soft and easily peeled off. In the case of trees, the rough bark is found to be of a dark, almost black, tint, and the green layer underneath has, as in the case of an herbaceous stem, been turned brown to a greater or less extent. In either case the plant has been practically "girdled," the effect being aggravated by the diseased sap poisoning, more or less, the whole stem and roots. The plant may not die, but it will be quite certain to become unprofitable to the grower.

It is mainly in the case of land very heavily charged with common salt, as in the marshes bordering the sea or salt lakes, that injury arises from the direct effects of the salty soil-water upon the feeding roots themselves. In a few cases the gradual rise of salt water from below, in consequence of defective drainage, has seriously injured, and even destroyed, old orange orchards.

The fact that in cultivated land the injury is usually found to occur near the surface of the soil, concurrently with the well-known fact that the maximum accumulation of salts at the surface is always found near the end of the dry season, indicates clearly that this accumulation is due to evaporation at the surface. The latter is often found covered with a crust consisting of earth cemented by the crystallized salts, and later in the season with a layer of whitish dust resulting from the drying-out of the crust first formed. It is this dust which becomes so annoying to the inhabitants and travelers in alkali regions, when high winds prevail, irritating the eyes and nostrils and parching the lips.

EFFECTS OF IRRIGATION.

One of the most annoying and discouraging features of the cultivation of lands in alkali regions is that, although in their natural condition they may show but little alkail on their surface, and that mostly in

limited spots, usually somewhat depressed below the general surface, these spots are found to enlarge rapidly as irrigation is practiced; and since alkali salts are the symptoms and result of insufficient rainfall, irrigation is a necessary condition of agriculture wherever they prevail. Under irrigation, neighboring spots will oftentimes merge together into one large one, and at times the entire area, once highly productive and perhaps covered with valuable plantations of trees or vines, will become incapable of supporting useful growth. This annoying phenomenon is popularly known as "the rise of the alkali" in the western United States, but is equally well known in India and other irrigation regions.

The process by which the salts rise to the surface is the same as that by which oil rises in a wick. The soil being impregnated with a solution of the alkali salts, and acting like the wick, the salts naturally remain behind on the surface as the water evaporates, the process only stopping when the moisture in the soil is exhausted. We thus not infrequently find that after an unusually heavy rainfall there follows a heavier accumulation of alkali salts at the surface, while a light shower produces no perceptible permanent effect. We are thus taught that, within certain limits, *the more water evaporates during the season the heavier will be the rise of the alkali;* provided that the water is not so abundant as to leach the salts through the soil and subsoil into the subdrainage.

Worst of all, however, is the effect of irrigation ditches laid in sandy lands (such as are naturally predominant in arid regions), without proper provision against seepage. The ditch water then gradually fills up the entire substrata so far as they are permeable, and the water-table rises from below until it reaches nearly to the ditch level; shallowing the subsoil, drowning out the deep roots of all vegetation, and bringing close to the surface the entire mass of alkali salts previously diffused through many feet of substrata. If this condition is allowed to continue for some time, alkali salts originally "white" will by a chemical change become "black" by the formation of carbonate of soda from the glauber and common salts; greatly aggravating the injury to vegetation. More than this, if such swamping is allowed to continue for a number of years, the land may be permanently injured; so that even after the alkali is removed, the soil remains inert and unthrifty for years.

DETERMINATION OF THE DISTRIBUTION OF THE ALKALI SALTS.

In order to gain a basis for the possible means of reclaiming alkali lands, it is evidently necessary to determine by direct observation the manner in which the salts are distributed in the soils under different conditions. This can be done by sampling the soil at short intervals of depth, and leaching out and analyzing each sample separately. While

this involves a great deal of work, it is manifestly the only conclusive method.

A series of such investigations has been first carried out by the California Experiment Station during the years 1894 and 1895, with samples taken in or near the substations near Tulare and Chino, Cal., with the results as given below. It should be understood that the alkali in the Tulare region is naturally mostly of the "black" kind, that is, consisting largely of carbonate of soda, which dissolves the humus of the soil and thus gives rise to dark-colored spots and inky water-puddles. The soil is a rather sandy, gray loam (see Report California Experiment Station, 1889). On the Chino tract, on the contrary, the soil is a close-grained, rather heavy loam, naturally subirrigated; the salts are likewise largely "black," the sodium carbonate being about one third of the whole.

Fig. 1 represents the condition of the salts in an "alkali spot" as found at the end of the dry season at the Tulare substation. The soil was sampled to the depth of two feet, at intervals of three inches each. The depths are entered in the vertical line to the left; the percentages of the total salts and of each of the principal ingredients ar entered in decimal fractions of one per cent on horizontal lines running to the right, as indicated on the top

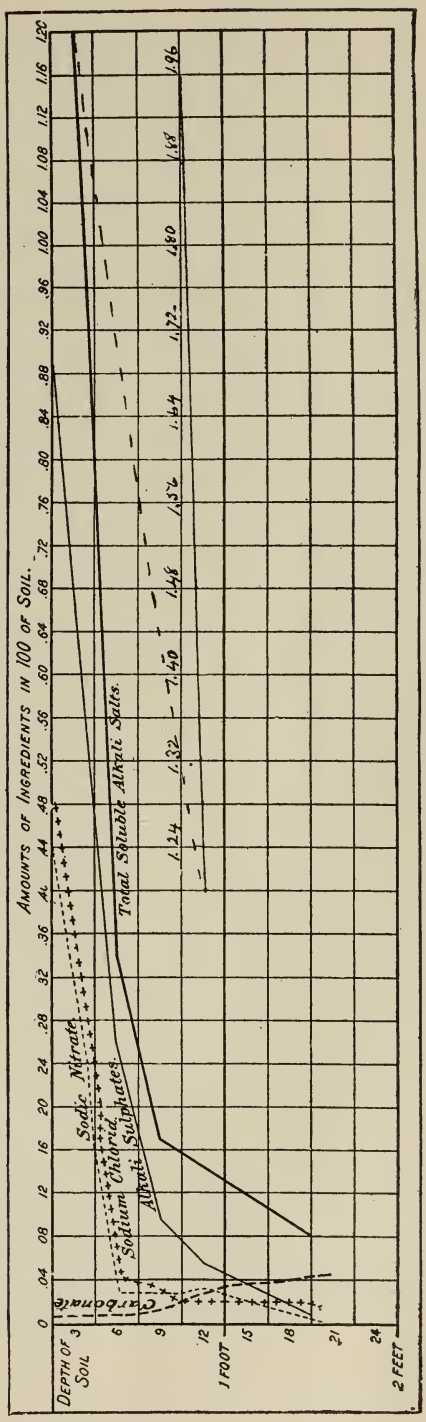

FIG 1. Diagram showing amount and composition of alkali salts at various depths in partially reclaimed sandy alkali land, on which barley grew 4 feet high. Taken September, 1894, Tulare Experiment Substation, California.

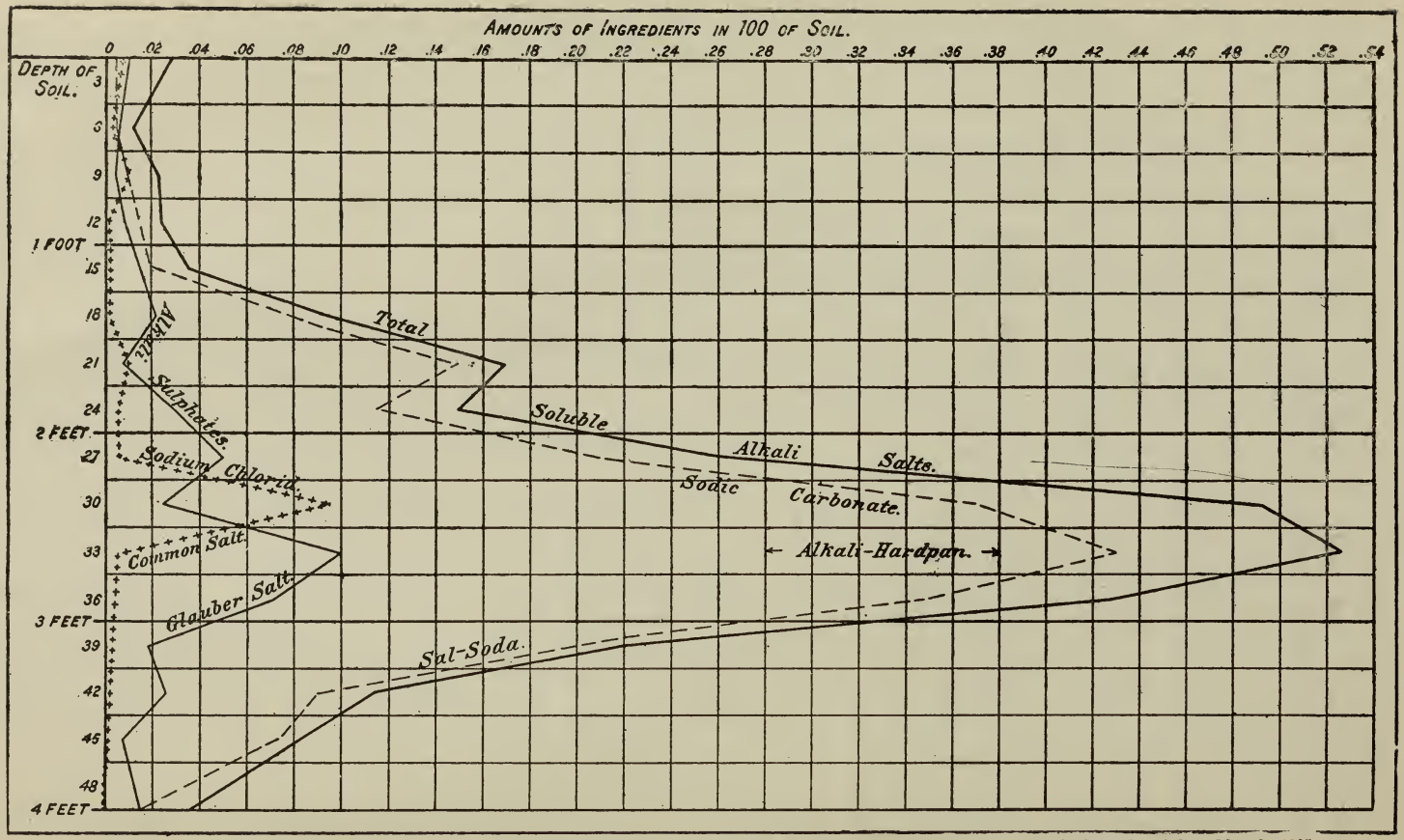

FIG. 2. Diagram showing amounts and composition of alkali salts at various depths in black alkali land, unirrigated. Taken March, 1895. Tulare Experiment Substation, California.

line of the plate. Broken lines connecting the data in each case facilitate the understanding of the results. It is thus easy to see that at this time almost the entire mass of the salts was accumulated within the first six inches from the surface, while lower down the soil contained so little that few culture plants would be hurt by them.

Fig. 2 represents similarly the state of things in a natural soil alongside of the alkali spot, but in which the native vegetation of brilliant flowers develops annually without any hindrance from alkali. Samples were taken from this spot in March, near the end of the wet, and in September, near the end of the dry, season, and each series fully analyzed. There was scarcely a noticeable difference in the results obtained. It is seen in the figure that down to the depth of fifteen inches there was practically no alkali found (0.035 per cent), and it was within these fifteen inches of soil that the native plants mostly had their roots and developed their annual growth. But from that level downward the alkali rapidly increased, and reached a maximum (0.529 per cent) at about thirty-three inches, decreasing rapidly thence until, at the end of the fourth foot in depth, there was no more alkali than within the first foot from the surface. In other words, the bulk of the salts had accumulated at the greatest depth to which the annual rainfall (7 inches) ever reaches, forming there a sheet of tough, intractable clay hardpan. The shallow-rooted native plants germinated their seeds freely on the alkali-free surface, their roots kept above the strongly charged subsoil, and through them and the stems and foliage all the soil moisture was evaporated by the time the plants died. Thus no alkali was brought up from below by evaporation. The seeds shed would remain uninjured, and would again germinate the coming season.

It is thus that the luxuriant vegetation of the San Joaquin plains, dotted with occasional alkali spots, is maintained, the spots themselves being almost always depressions in which the rain water may gather, and where, in consequence of the increased evaporation, the noxious salts have risen to the surface and render impossible all but the most resistant saline growth; particularly when, in consequence of maceration and fermentation in the soil, the formation of carbonate of soda (black alkali) has caused the surface to sink and become almost water-tight.

After several years' cultivation with irrigation on the same land as in the last figure, a crop of barley four feet high was grown on the land. Investigation proved that here the condition of the soil was intermediate between the two preceding figures. The irrigation water had dissolved the alkali of the subsoil, and the abundant evaporation had brought it nearer the surface; but the shading by the barley crop and the evaporation of the moisture through its roots and leaves had prevented the salts from reaching the surface in such amounts as to injure the crop, although the tendency to rise was clearly shown.

Ten feet from this spot was bare alkali ground on which barley had refused to grow. Its examination proved it to contain a somewhat larger proportion (one-fifth more) of alkali salts, and in these a larger relative proportion of carbonate of soda (salsoda). Thus the seed was mostly destroyed before germination, and of the few seedlings none lived beyond the fourth leaf. On the ground represented by Fig. 1, previous treatment with gypsum had so far diminished the salsoda that the grain germinated freely, and a very good crop of barley was

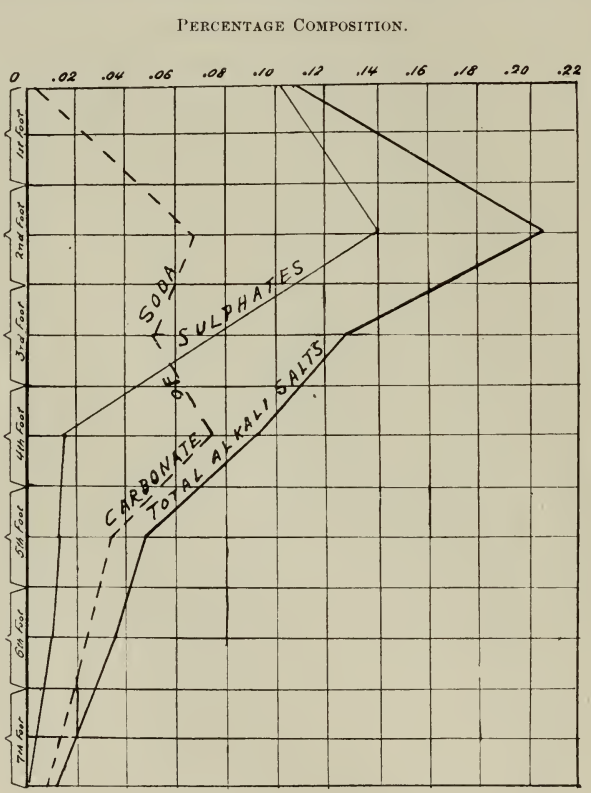

FIG. 3. Distribution of alkali salts in sandy land.

harvested there without irrigation. The same season, grain crops were almost a failure on alkali-free land in the same region.

In connection with this result it should be noted as a general fact that *alkali lands always retain a certain amount of moisture* perceptible to the hand during the dry season, and that *this moisture can be utilized by crops;* so that at times when crops fail on nonalkaline land, good ones are obtained where a slight taint of alkali exists in the soil. Striking examples of this fact occur in the Spokane country within the great bend of the Columbia River, in the State of Washington; and the same is illustrated by the luxuriant growth of weeds on the margin of

alkali spots, just beyond the limit of corrosive injury. Actual determination showed that while a sample of alkali soil containing .54 per cent of salts absorbed 12.3 per cent of moisture from moist air, the same soil when leached absorbed only 2.5 per cent—a figure corresponding to that of sandy upland loams. Investigation at the Tulare substation during the dry season of 1898 also showed the presence of 15 and 16 per cent of water, respectively, in strong "white" and "black" alkali soils, while in adjoining light alkali soils there was but 10 per cent.

In *very* sandy lands, and particularly when the alkali is "white" only, the tendency to accumulation near the surface is much less, even

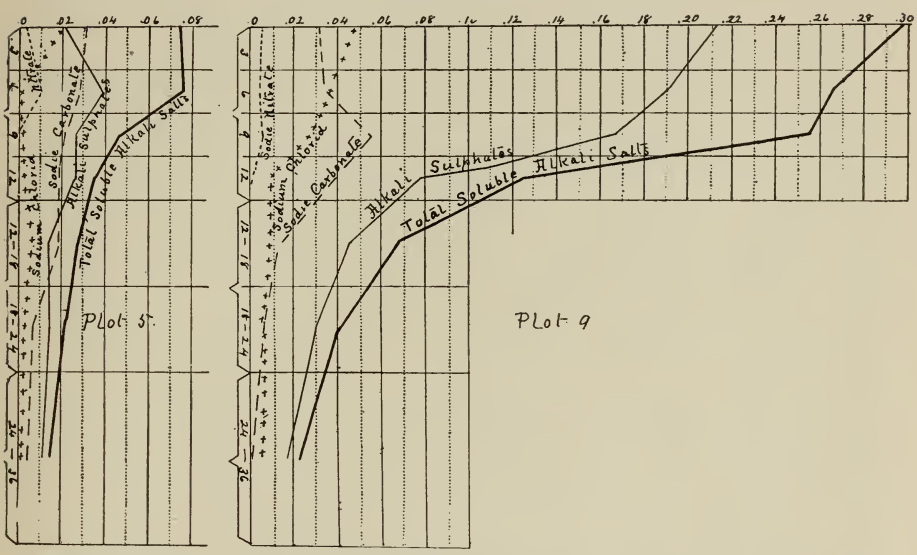

FIG. 4. Distribution of alkali salts in close-textured soil of the 10-acre tract, near Chino, Cal.

under irrigation. In the natural condition the salts are in such cases often found quite evenly distributed through soil columns of four feet, and even more. This is an additional cause of the lesser injuriousness of "white" alkali.

Fig. 3 shows the distribution of the salts as found in a very sandy area on the Tulare substation grounds. It should be noted that here, while the general figure representing the distribution is very similar to that showing the same in a close soil (see Fig. 4) the salts reach down to over six feet, and are at their maximum eighteen inches from, instead of *at* the surface.

The mode of distribution of alkali salts in the heavier, close-grained soil of the Chino tract is illustrated in Fig. 4. As has been mentioned, this land is permanently moist, from a water-table ranging from five to

seven feet below the surface in ordinary years. There is therefore no opportunity for the formation of "alkali hardpan" as in the case of the Tulare soil; the salts always remain rather near the surface, viz, within twelve to eighteen inches. But being in much smaller average amounts than at Tulare (an average of about 5,300 pounds per acre), quite a copious natural vegetation of grasses, sunflowers, and "yerba mansa" originally covered the whole surface, save in a few low spots.

A similar mode of distribution of the salts is found in the more clayey "black adobe" lands of the Great Valley of California. The scanty rains can not penetrate these soils to any great depth, so that evaporation will soon bring the salts carried by them back to within a short distance of the surface. Their accumulation there is frequently indicated by the entire absence of any but the most resistant alkali weeds, even though the total of salts in the land may not be very great.

While the phenomena of alkali lands as outlined above undoubtedly represent the vastly predominant conditions on extensive level lands, yet there are exceptions due to surface conformation, and to the local existence of sources of alkali salts outside of the soil itself. Such is the case where salts ooze out of strata cropping out on hillsides, as is the case at some points in the San Joaquin Valley in California, and in parts of Colorado, Wyoming, and Montana. In such cases the alkali salts may be most apparent near the foot of the hills, and in light, well-drained valley lands may disappear altogether before reaching the valley-trough.

On the other hand, it not infrequently happens that in sloping valleys or basins, where the central (lowest) portion receives the salts leached out of the adjacent hills and valley slopes in consequence of slow subdrainage, we find belts of greater or less width in which the alkali impregnation may reach to the depth of ten or twelve feet, usually within more or less definite layers of calcareous hardpan, likewise the outcome of the leaching of the valley slopes. Such areas, however, are usually quite limited, and are, of course, scarcely reclaimable without excessive expenditure, the more as they are often underlaid by saline bottom water. In these cases the predominant saline ingredient is usually common salt, as might be expected, and as is exemplified on a large scale in the Great Salt Lake of Utah, and in the ocean itself.

In many cases, in California and elsewhere, the over-irrigation of bench or slope lands has caused, first the lower slopes, and then the bottom lands of streams and rivers, to be overrun with alkali salts, although before irrigation was practiced these lands were exempt from them. In some portions of the San Joaquin Valley this trouble has become most serious, fertile lands long under successful cultivation being rendered useless by thousands of acres, unless an expensive

system of underdrainage were resorted to. Even this remedy is largely inapplicable in the absence of legislation providing for right-of-way for drainage as well as for irrigation; but any such legislation should, at the same time, provide a remedy for the leakage of ditch-water, which is the original cause of the injury.

COMPOSITION OF ALKALI SALTS.

Broadly speaking, it may be said that, the world over, alkali salts consist of three chief ingredients, namely, *common salt, glauber salt* (sulfate of soda), and *salsoda* or *carbonate of soda.* The latter causes what is popularly known as "black alkali," from the black spots or puddles seen on the surface of lands tainted with it, owing to the dissolution of the soil humus; while the other salts, often together with epsom salt, constitute "white alkali," which is known to be very much milder in its effect on plants than the black. In most cases all three are present, and all may be considered as practically valueless or noxious to plant growth. Sulfate of magnesia (epsom salt) and the chlorids of magnesium and calcium are also not uncommon, especially in the interior region—Montana, Wyoming, Colorado, Utah, and New Mexico, where the first-named sometimes forms the predominant ingredient. They also are found in California.

With these noxious salts, however, there are almost always associated, in varying amounts, sulfate of potash, phosphate of soda, and nitrate of soda, representing the three elements—potassium, phosphorus, and nitrogen—upon the presence of which in the soil, in available form, the welfare of our crops so essentially depends, and which we aim to supply in fertilizers. The potash salt is usually present to the extent of from 5 to 20 per cent of the total salts; phosphate, from a fraction to as much as 4 per cent; the nitrate, from a fraction to as much as 20 per cent. In black alkali the nitrate is usually low, the phosphate high; in the white, the reverse is true.

It is thus clear that if we were to make a rule of reclaiming alkali lands by leaching out the salts with an abundance of irrigation water, we would get rid not only of the noxious salts, but also of those ingredients upon which productiveness primarily depends, and for which we pay heavily in fertilizers. This is evidently to be avoided, if possible.

Summing up the conclusions from the foregoing observations and considerations we find that—

(1) The amount of soluble salts in alkali soils is usually limited; they are not ordinarily supplied in indefinite quantities from the bottom water below. These salts have mostly been formed by weathering, in the soil layer itself.

(2) The salts ordinarily move up and down within the upper four or five feet of the soil and subsoil, following the movement of the moisture; descending in the rainy season to the limit of the annual moistening as a maximum, and then reascending or not according as surface evaporation may demand. At the end of the dry season, in untilled irrigated land, practically the entire mass of salts may be within six or eight inches of the surface.

(3) The injury to vegetation is caused mainly, sometimes wholly, within a few inches of the surface, by the corrosion of the bark, usually near the root crown. This corrosion is strongest when carbonate of soda (salsoda) forms a large proportion of the salts; the soda then also dissolves the vegetable mold and causes blackish spots in the soil, popularly known as black alkali.

(4) The injury caused by carbonate of soda is aggravated by its action in puddling the soil so as to cause it to lose its flaky condition, rendering it almost or quite untillable. It also tends to form in the depths of the soil layer a tough hardpan, impervious to water, which yields to neither plow, pick, nor crowbar, and renders drainage and leaching impossible. Its presence is easily ascertained by means of a pointed steel sounding rod.

(5) While alkali lands share with other soils of the arid region the advantage of unusually high percentages of plant-food in the insoluble form,* they also contain, alongside of the noxious salts, considerable amounts of water-soluble plant-food. When, therefore, the action of the noxious salts is done away with, they should be profusely and lastingly productive; particularly as they are always naturally somewhat moist in consequence of the attraction of moisture by the salts, and are therefore less liable to injury from drought than the same soils when free from alkali.

UTILIZATION AND RECLAMATION OF ALKALI LANDS.

The most obvious mode of utilizing alkali lands is to occupy them with useful plants that are not affected by the noxious salts. Unfortunately, as has already been stated, but few such crops of general utility, especially for the commercial and labor conditions of this country, have as yet been found. Practically the most important problem is to render these lands available for our ordinary cultures, by methods financially possible.

Counteracting Evaporation.—Since evaporation of the soil moisture at the surface is what brings the alkali salts to the level where the main injury to plants occurs, it is obvious that evaporation should be

*See Bulletin No. 3 of the U. S. Weather Bureau, 1892; Report California Station, 1894-5.

prevented as much as possible. This is the more important, as the saving of soil moisture, and therefore of irrigation water, is attainable by the same means.

Three methods for this purpose are usually practiced by farmers and gardeners, viz, shading, mulching, and the maintenance of loose tilth in the surface soil to such depth as may be required by the climatic conditions.

Mulching is already well recognized in the alkali regions of California as an effective remedy in light cases. Fruit trees are frequently thus protected, particularly while young, after which their shade alone may (as in the case of low-trained orange trees) suffice to prevent injury. The same often happens in the case of low-trained vines, small fruits, and vegetables. Sanding of the surface to the depth of several inches was among the first attempts in this direction; but the necessity of cultivation, involving the renewal of the sand each season, renders this a costly method. Straw, leaves, and manure have been more successfully used; but even these, unless employed for the purpose of fertilization, involve more expense and trouble than the simple *maintenance of very loose tilth of the surface soil throughout the dry season;* a remedy which, of course, is equally applicable to hoed field crops, and in the case of some of these—e. g., cotton—is a necessary condition of cultural success everywhere. The wide prevalence of "light" and deep soils in the arid regions, from causes inherent in the climate itself,* renders this condition of relatively easy fulfillment.

Diluting the Alkali Salts.—Aside, however, from the mere prevention of surface evaporation, another favorable condition is realized by this procedure, namely, the commingling of the heavily salt-charged surface layers with the relatively nonalkaline subsoil. Since in the arid regions the roots of all plants retire farther from the surface because of the deadly drought and heat of summer, it is possible to cultivate deeper than could safely be done with growing crops in humid climates. Yet even here, the maxim of "deep preparation and shallow cultivation" is put into practice with advantage, only changing the measurements of depth to correspond with the altered climatic conditions. Thus, while in the eastern United States four inches is the accepted standard of depth for summer cultivation to preserve moisture without injury to the roots, that depth must in the arid region frequently be doubled in order to be effective, and will even then scarcely touch a living root in orchards and vineyards in unirrigated land.

A glance at Fig. 1 (p. 9) will show the great advantage of extra deep preparation in commingling the alkali salts accumulated near the surface with the lower soil layers, diffusing the salts through twelve

*See reference on preceding page.

instead of six inches of soil mass. This will in very many cases suffice to render the growth of ordinary crops possible if, by subsequent frequent and thorough cultivation, surface evaporation, and with it the reascent of the salts to the surface, is prevented. A striking example of the efficiency of this mode of procedure was given at the Tulare substation, where a portion of a very bad alkali spot was trenched to the depth of two feet, throwing the surface soil to the bottom. The spot thus treated produced excellent wheat crops for a few years—the time it took the alkali salts to reascend to the surface.

It should therefore be kept in mind that whatever else is done toward reclamation, *deep preparation* and *thorough surface cultivation* must be regarded as prime factors for the maintenance of production on all alkali lands.

The efficacy of *shading*, already referred to, is strikingly illustrated in the case of some field crops which, when once established, will thrive on fairly strong alkali soil, provided that a good thick "stand" has once been obtained. This is notably true of the great forage crop of the arid region, alfalfa, or lucern. Its seed is extremely sensitive to black alkali, and will decay in the ground unless protected against it. But when once a full stand has been obtained, the field may endure for many years without a sign of injury. Here two effects combine, viz, the shading, and the evaporation through the deep roots and abundant foliage, which alone prevents, in a large measure, the ascent of the moisture to the surface. The case is then precisely parallel to that of the natural soil (see Fig. 2), except that, as irrigation is practiced in order to stimulate production, the sheet of alkali hardpan will be dissolved and its salts spread through the soil more evenly. The result is that oftentimes, so soon as the alfalfa is taken off the ground and the cultivation of other crops is attempted, an altogether unexpectedly large amount of alkali comes to the surface and greatly impedes, if it does not altogether prevent, the immediate planting of other crops. Shallow-rooted annual crops that give but little shade, like the cereals, while measurably impeding the rise of the salts during their growth, frequently allow of enough rise after harvest to prevent reseeding the following season.

Chemical Remedies.—Of the three sodium salts that usually constitute the bulk of "alkali," only the carbonate of soda is susceptible of being materially changed by any agent that can practically be applied to land. So far as we know, the salt of sodium least injurious to ordinary vegetation is the sulfate, commonly called glauber salt, which ordinarily forms the chief ingredient of white alkali. Thus barley is capable of resisting about five times more of the sulfate than of the carbonate, and quite twice as much as of common salt. Since the

maximum percentage that can be resisted by plants varies materially with the kind of soil, it is difficult to give exact figures save with respect to particular cases. For the sandy loam of the Tulare substation the maximum for cereals may be approximately stated to be one tenth of one per cent (0.1) for salsoda, a fourth of one per cent (0.25) for common salt, and from forty-five to fifty one hundredths of one per cent (0.45-.50) for glauber salt, within the first foot from the surface. For clay soils the tolerance is markedly less, especially as regards the salsoda, since in their case the injurious effect on the tilling qualities of the soil, already referred to, is superadded to the corrosive action of

FIG. 5. Wheat growing 3 feet high in soil crusted with white alkali, originally a barren black-alkali spot but reclaimed with gypsum. Tulare Experiment Substation.

that salt; and in them, moreover, accumulation at the surface is more pronounced.

Since, then, so little carbonate of soda suffices to render soils uncultivable, it frequently happens that its mere transformation into the sulfate is sufficient to remove all stress from alkali. Gypsum (land-plaster) is the cheapest and most effective agent to bring about this transformation, *provided water be also present.* The amount required per acre will, of course, vary with the amount of carbonate of soda in the soil, all the way from a few hundred pounds to several tons in the case of strong alkali spots. But it is not usually necessary to add the entire quantity at once, provided that sufficient be used to *neutralize the alkali near the surface,* and enough time be allowed for the action to take place. In very wet soils this may occur within a few days; in merely damp soils, in the course of months; but usually the

effect increases for years, as the salts rise from below. For the complete neutralization of each 1,000 pounds of carbonate of soda in the land, 1,630 pounds of pure gypsum is required. But of the impure, 80-85 per cent article as now on the market in California, an even double quantity, or 2,000 pounds, would be the proper dose.

The effect of gypsum on the black-alkali soil of Tulare substation was to change a barren spot into a tract which produced a fine crop of wheat, although the surface of the soil was covered with a crust of the white alkali (sulfate of soda). This is shown in the photograph (Fig. 5) on preceding page.

The effect of gypsum on black alkali land is often very striking, even to the eye. The blackish puddles and spots disappear, because the gypsum renders the dissolved humus insoluble and thus restores it to the soil. The latter soon loses its hard, puddled condition and crumbles and bulges into a loose mass, into which water now soaks freely, bringing up the previously depressed spots to the general level of the land, and permitting free subdrainage. On the surface thus changed seeds now germinate and grow without hindrance; and as the injury from alkali occurs at or near the surface, it is usually best to simply harrow-in the plaster, leaving the water to carry it down in solution. Soluble phosphates present are decomposed, so as to retain finely divided but less soluble phosphates in the soil.

Trees and vines already planted may be temporarily protected from the worst effects of the black alkali by surrounding the trunks with gypsum or with earth abundantly mixed with it. Seeds may be similarly protected in sowing, and plants in planting.

It must not be forgotten that this beneficial change effected by the gypsum may go backward if the land thus treated is permitted to be swamped by excess of irrigation water or otherwise. Under the same conditions alkali naturally white may turn to black; and no amount of gypsum used can prevent or undo this until the excess of water is drained off and the soil allowed time for aëration. Thus while excessive irrigation is injurious at all times in diminishing the death of root-growth and the feeding area of the plant, it is especially injurious when alkali is present.

Of course gypsum is of no benefit whatever on soils containing no salsoda, but only glauber and common salt.

Stable Manure and Other Fertilizers.—Under the impression that alkali land is poor in plant-food, farmers frequently try applications of stable manure and other fertilizers. As a rule these applications are not only useless, but even harmful. From their very mode of formation, alkali lands are exceptionally rich in plant-food, so that the addition of more can do no good. In the case of stable manure being

used on black alkali ground, a pungent odor of ammonia is given off whenever the sun shines, and plants otherwise doing well are thus injured or killed. When well plowed-in, stable manure will sometimes prevent to some extent the rise of the alkali by diminishing evaporation; but its usefulness in that respect is readily replaced by good tillage. The main benefit obtained is the addition of humus to soils that have been whitened by alkali action.

Potash salts, especially kainit, are wholly useless and add to the alkali trouble; potash is always abundantly present in alkali lands, even in the water-soluble condition. Nitrates, also, are always present in alkali soils in sufficient amounts for plant growth, sometimes to excess. Phosphates may sometimes be useful, but will rarely be needed for some years. Greenmanuring, on the other hand, is a very desirable improvement on all alkali lands.

REMOVING THE SALTS FROM THE SOIL.

In case the amount of salts in the soil should be so great that even the change worked by gypsum is insufficient to render it available for useful crops, the only remedy left is to remove the salts partially or wholly from the land.

Two chief methods are available for this purpose. One is to remove the salts, with more or less earth, from the surface at the end of the dry season, either by sweeping, or by means of a horse scraper set so as to carry off a certain depth of soil. Thus sometimes in a single season one third or one half of the total salts may be got rid of, the loss of a few inches of surface soil being of little moment in the deep soils of the arid region. On small tracts, as in gardens, this can be very effectively done.

The other method is to leach down the salts by flooding; either into the country drainage, which will afford definitive relief, supplementing by irrigation water what is left undone by the deficient rainfall; or else to a depth sufficient to allow seeds to sprout so as to produce a good stand without injury from alkali, and then to keep the latter down by means of irrigation in deep furrows—the use of shallow furrows as usually made will rapidly bring the salts to the surface again by evaporation—or in the case of broadcast cultures, by repeated flooding. When the salts have once been washed down to the depth of several feet by flooding, the conscientious practice of deep-furrow irrigation can be made to keep them out of reach indefinitely, or until underdrains can be afforded.

It is not practicable, as many suppose, to wash the salts off the surface by a rush of water, as they instantly soak into the ground at the first touch. Nor is there any sensible relief from allowing the water to

stand on the land and then drawing it off; in this case also the salts soak down ahead of the water, and the water standing on the surface remains almost unchanged. In very pervious soils, and in the case of white alkali, the washing-out can often be accomplished without special provision for underdrainage, by leaving the water on the land sufficiently long. But the laying of regular underdrains greatly accelerates the work, and renders success certain. In the case of black alkali, however, either the impervious hardpan or (in the case of actual alkali spots) the impenetrability of the surface soil itself will render even underdrains ineffective unless the salsoda and its effects on the soil are first destroyed by the use of gypsum, as above detailed. This is not only necessary in order to render drainage and leaching possible, but is also advisable in order to prevent the leaching-out of the valuable humus and soluble phosphates, which are rendered insoluble (but not unavailable to plants) by the action of the gypsum. Wherever black alkali is found, in considerable proportion, the application of gypsum should precede any and all other efforts toward reclamation.

Another method for diminishing the amount of alkali in the soil is the cropping with plants that take up considerable amounts of salts. In taking them into cultivation, it is advisable to remove entirely from the land the salt growth that may naturally cover it, notably the bushy samphire and greasewood (*Allenrolfea, Sarcobatus*), with their heavy percentages of alkaline ash. Crop plants adapted to the same object are mentioned farther on.

The effect of removing the alkali salts from the surface soil to a depth beyond the tree roots by the liberal use of irrigation water was well shown in a lemon orchard near La Mirada, Los Angeles County, where some of the trees were badly stunted by the presence of about 3,800 pounds of carbonate of soda and common salt. The manager, by an excessive use of water, dissolved the salts and caused them to be carried down deeply beyond the roots, and the result shortly was apparent in the improved growth and condition of the trees. The accompanying photographs were taken before and after the treatment, and the change from poor to good condition is well shown.

WILL IT PAY TO RECLAIM ALKALI LANDS?

This is a question naturally asked when considering the nature and expense of the operation involved, especially when the last resort—underdraining and leaching—has to be adopted.

Those familiar with the alkali regions are aware how often the occurrence of alkali spots interrupts the continuity of fields and orchards, of which they form only a small part, but enough to mar their aspect and cultivation. Their increase and expansion under irrigation

FIG 6. Lemon orchard affected by alkali before deep irrigation.

FIG. 7. The above orchard after alkali was driven down by deep irrigation, followed by cultivation.

frequently render their reclamation the only alternative of absolute abandonment of the investments and improvements made, and from that point of view alone it is of no slight practical importance. Moreover, the occurrence of vast continuous stretches of alkali lands within the otherwise most eligibly situated portions of the irrigation region forms a strong incentive toward their utilization.

There is, however, a strong intrinsic reason pointing in the same direction, namely, the almost invariably high and lasting productiveness of these lands when once rendered available to agriculture. This is foreshadowed by the usually very heavy and luxuriant growth of native plants around the margins of and between alkali spots (see Fig. 8); that is, wherever the amount of injurious salts present is so small as not to interfere with the utilization of the abundant store of plant-food which, under the peculiar conditions of soil formation in arid climates, remains in the land instead of being washed into the ocean. Extended comparative investigations of soil composition, as well as the experience of thousands of years in the oldest settled countries of the world, demonstrate this fact and show that, so far from being in need of fertilization, alkali lands possess extraordinary productive capacity whenever freed from the injurious influence of the excess of useless salts left in the soil in consequence of deficient rainfall. Alkali salts are actually scraped up and carried to the cultivated fields in sacks in parts of Turkestan, the peasants considering that "the salt is the life of the land." (Middendorf.)

It does not, of course, follow that alkali lands are good lands for farmers of limited means to settle upon. On the contrary, like most other business enterprises, they require a certain amount of capital and lapse of time to render them productive. They are not, therefore, a proper investment for farmers or settlers of small means, dependent on annual crops for their livelihood and unable to bring to bear upon these soils the proper means for their reclamation; unless, indeed, local conditions should enable them to use successfully some of the crops specially adapted to alkali lands.

CROPS SUITABLE FOR ALKALI LANDS.

As has already been stated, the search for generally available crops that will thrive in strong, unreclaimed alkali land has not thus far been very successful. It is true that cattle will nibble alkali grass (*Distichlis spicata*), but will soon leave it for any dry food that may be within reach. The same is true of all the fleshy plants that grow on the stronger alkali lands, and are known under the general designation of alkali weeds. When stock unaccustomed to it are forced by hunger to feed on such vegetation to any considerable extent, disordered

FIG. 8. Alkali lands in San Joaquin Valley, California.

digestion is apt to result; which, in such ranges, however, is often counteracted by feeding on aromatic or astringent antidotes, such as the gray sagebrush and the more or less resinous herbage of plants of the sunflower family. In the Great Basin region, lying between the Sierra Nevada and the front range of the Rocky Mountains, there are, aside from the grasses, numerous herbaceous and shrubby plants that afford valuable pasturage for stock,* and some of these grow on moderately strong alkali land; the same is true in California. It is quite possible that some of these will be found to lend themselves to ready propagation for culture purposes as well as they do for restocking the ranges. But thus far none have found wider acceptance, probably because their stiff branches and upright habit render them inconvenient to handle. It will require more extended experience and experiment before any of these can be definitely adopted by farmers.

Experience in California indicates that in the more southerly portion of the arid region the unpalatable native plants may be generally replaced, even on the ranges, by one or more species of the Australian saltbushes (*Atriplex* spp.), long ago recommended by Baron von Mueller of Melbourne; of which one (*A. semibaccata*) has proved eminently adapted to the climate and soil of California and is readily eaten by all kinds of stock. The facility with which it is propagated, its quick development, the large amount of feed yielded on a given area, even in the strongest alkali land ordinarily found, and its thin, flexible stems, permitting it to be handled very much like alfalfa, seem to commend it especially to the farmer's consideration wherever the climate will permit of its use. Its resistance to severe cold weather has not yet been adequately tested. It is probable that other species, now also under trial, will equally justify the recommendation given them by the eminent botanist who first brought them into public notice as promising forage plants. Most of the species have an upright, shrubby habit which adapts them rather to browsing than to use as a forage crop. Among the best next to the *semibaccata* are the species *leptocarpa* and *halimoides*, the former somewhat similar in habit to the *semibaccata* but not so rapid a grower. The *A. nummularia* (old-man saltbush), highly valued and recommended in Australia and Algeria, is not liked by California stock; but the species *cachiyouyo*, introduced from Argentina, seems to be palatable to all kinds of stock, and but for its tall, upright habit, would be among the most acceptable of the saltbushes, being very productive.

A special bulletin on the saltbushes, Australian as well as native, has been published by this Station and will be sent on request.

*See Bulletin No. 16 of the Wyoming Experiment Station; also Bulletins Nos. 2 and 12 of the Division of Agrostology, and Farmers' Bulletin No. 108, U. S. Department of Agriculture.

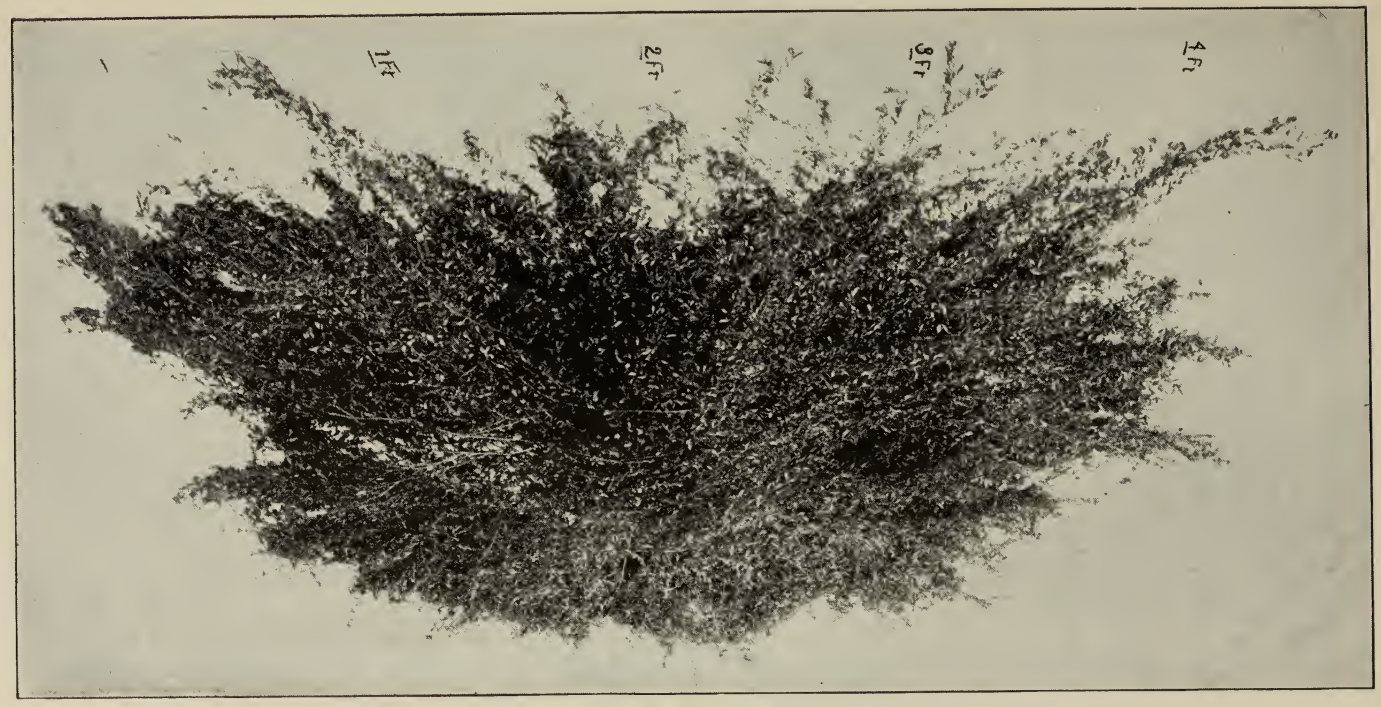

FIG. 9. Australian saltbush (*A. semibaccata*). Natural spread from single stalk.

It is to be noted that since the saltbushes take up nearly one fifth of their dry weight of ash ingredients,* largely common salt, the complete removal from the land of a five-ton crop of saltbush hay will take away nearly a ton of the alkali salts per acre. This will in the course of some years be quite sufficient to reduce materially the saline contents of the land, and will frequently render possible the culture of ordinary crops.

Next to the saltbushes the Chilean plant *Modiola decumbens* (now commonly known as modiola simply), of the mallow family, deserves attention. Accidentally introduced as a weed with other seeds, by the Kern County Land Company at Bakersfield, it attracted attention by its persistence on alkali lands, and by the observation that cattle ate it freely. It was then grown on a larger scale, and found to make acceptable pasture where alfalfa could not be grown on account of alkali. It is a trailing plant, with medium-sized, roundish foliage, and roots freely at the joints where they touch the ground. Unlike the saltbushes it is therefore a formidable weed where it is not wanted; but as, according to our determinations, it resists as much as 52,000 pounds of salts per acre, even when 41,000 of these is common salt, it is likely to be useful in many cases, particularly as an admixture to a saltbush diet for stock, the more as it does not absorb as much salt as the latter. Owing to the rooting habit of the stems, it is not as convenient to handle as the *semibaccata* saltbush, nor, probably, will it yield as much fodder in a season. It seems best adapted to pasturage.

Another forage plant which it may hereafter pay to propagate artificially on strong alkali land, is the tussock-grass (*Sporobolus airoides*), of which a figure is given on page 63. Indicating as it usually does when growing naturally, land too strongly impregnated to be reclaimable at this time, but being freely eaten by stock, it seems worth while to count it among the possible pasture grasses for land too strongly alkaline to bear ordinary crops. Its seed can be abundantly gathered in its native habitats, indicated below.

TOLERANCE OF ALKALI BY VARIOUS CULTURES.

In 1898-1900 we made special investigations on this subject and have endeavored to ascertain, as far is possible, the highest amount of each salt occurring in four feet depth in which the different cultures of all kinds—orchard, as well as others—will grow and come to maturity; for while it is true that it is the alkali within the first foot or two of the surface that is liable to produce the chief injury upon the roots

*Analyses made at the California station show 19.37 per cent of ash in the air-dry matter of Australian saltbush. (See California Sta. Bul. 105; E. S. R., vol. 6, p. 718.) Analyses of Russian thistle have been reported showing over 20 per cent of ash in dry matter. (See Minnesota Sta. Bul. 34; Iowa Sta. Bul. 26; E. S. R., vol. 6, pp. 552, 553.)

of the plants, it is certain that there will come a time in the cultivation of the land when nearly all of the salts that lie in the lower depths of the soil will be reached and dissolved by the water that has been given to the soil either by rainfall or by irrigation in sufficient amounts to percolate downward to it, and will be brought up and concentrated at or near the surface. This has occurred in the substations at Tulare and Chino.

It is this concentration that has proved so destructive to many cultures that for a time have done well; and it is this total amount within reach of water that must be considered when orchard trees or perennial crops are planted, if the farmer wishes to avoid the agony of seeing his work and hopes of years swept away by the sudden activity of an enemy which has been hidden in the lower depths of his land.

All of this injury to cultures was at first naturally attributed either to the content of carbonate of soda in the surface foot, where its corrosive action on the tender bark of the root crown could be felt, or to the very large amount of total salts which might produce stagnation of the sap or other injury to the feeding rootlets. Some analyses and observations were made at that time both on the amounts of alkali which caused suffering, and on the amounts in soils where no trouble appeared; the results are given in previous reports.

The depth of four feet has been adopted as the proper one, because investigations in the San Joaquin Valley and in the valley of southern California have shown that in all but the sandiest of soils the substrata below that depth, while not entirely free from alkali salts, contain so little and are so commonly beyond the depth to which rainfall or irrigation water penetrates or the effect of subsequent surface evaporation is felt, that the consideration of their content of alkali is unimportant.

Field of Observation.—The Tulare and Southern California substations have thus far been almost the only fields of observation, while experiments on reclamation problems have been conducted at the former station at the same time.

The Tulare tract was originally chosen for the purpose of making its alkali land the subject of special study and investigation; and at that time but one large alkali spot was in sight on the surface, the rest being covered with native grasses and wildflowers. Alkali hardpan, however, did exist at depths of from twelve to thirty-six inches, and the necessary use of irrigation water has, by percolation to the alkali and subsequent capillary rise, brought the dissolved salts to the surface here and there over the tract, and produced a number of gradually enlarging alkali spots. This gave a larger field of reclamation work than had been intended at first, while at the same time enlarging the scope of observation on various cultures. The effect of this rise of alkali was seen

in the blighted appearance of tree growths and other cultures that had at first been doing well, as well as in the bare spots so characteristic of "black alkali."

Reclamation of the black alkali has been carried on for a number of years, gypsum being applied, turned under and thoroughly watered. The result has been a very general conversion of the dreaded carbonate of soda into the far less harmful sulfate; and on spots where not a blade of grass would previously grow, there have been produced excellent wheat and barley, three or four feet high and full-headed, although the surface of the ground was at harvest time covered by a thick crust of white alkali. (See Fig. 5, page 19.)

Extent of the Investigation.—About one hundred varieties of cultures have been studied; these embrace orchard trees, grain and forage crops, grasses, vegetables, and other miscellaneous growths. The greater part of the results are valuable toward reaching the end in view, but others were disappointing in that the soils showed a far less amount of alkali salts than was indicated by surrounding conditions.

In many cases, several localities were chosen for the examination of the soil of the same culture, for it is impossible to judge of the nature and extent of alkali soils by the eye alone. For instance, many alfalfa fields in several parts of the State were sampled before conclusions at all satisfactory were reached, the majority having less than we had reason to believe.

The samples have all been carefully taken, each foot of the vertical soil-column being carefully mixed, in order that its sample may be an average of that foot. Many hundred analyses have been made with the assistance of Messrs. Colby, Snow, Lea, and Werthmueller.

A quick and at the same time accurate method of extracting the alkali from the soil has been adopted; instead of placing the dry soil on a filter and washing all of the alkali out with water, which often required two or more weeks in clay soils because of puddling by the carbonate of soda, a weighed amount is mixed with a measured quantity of water and allowed to digest for twenty-four hours with frequent shaking. The salts thus dissolved are thoroughly diffused through the liquid, and an aliquot part may be taken for evaporation and examination. If necessary, a portion may be passed through a filter to clear it from sediment, but very often the solution settles perfectly clear.

Difficulties in Interpretation of Results.—There are a number of conditions which may affect the interpretation of the results of alkali examinations and lead to erroneous conclusions with regard to the effect of alkali on cultures. These are climatic conditions, the possible presence of insects or diseases, imperfect physical conditions in the soil and subsoil, such as hardpan, high water-table, shallowness of the soil,

lack of ventilation and aëration, poor moisture supply, etc., any of which might cause intense suffering on the part of the plant. All of these must be considered before alkali can be charged with the trouble. Then when we come to consider the alkali itself we are met by its complexity and variability in composition, and it is only by a process of elimination that definite conclusions can be reached. It is easy enough to make tables showing the highest amount of each salt thus far found to be tolerated by the different cultures, but it is often very difficult to say positively that the death or suffering on the part of a culture is due to the presence of a certain salt, for other salts are always present in large or small amounts. When, however, the amount of one of the constituents is far below, and that of another is much above the amount tolerated by the plant elsewhere, it is quite safe to conclude that any distress on the part of the plant is due to the latter; provided, of course, that physical conditions of the soil are favorable to the life of the plant. In some cases where the amount of a certain salt was enormous, there could be but little doubt that the suffering of the plant was due to it; but the *lowest* limit of such intolerance is as yet undetermined.

The following tables give some of the results obtained by the analysis of the alkali soils bearing various crops, the effort being to select such as were typical of the effect and non-effect of alkali upon the growth. While the samples were actually examined for each foot in depth, it has been thought best for this bulletin to give only the average of the entire column as a whole, especially for the orchard trees whose roots penetrate deeply into the soil when free to do so. For smaller cultures, whose roots are chiefly found in the upper two feet of the soil, we give results for each of the two feet and the total found in four feet; otherwise the results would prove very puzzling and conflicting. The results are briefly discussed for each culture and a comparative summary of maximum tolerance is given in tabular form at the end of the bulletin.

We do not present all of the soils whose examinations have been made, but only those of most importance in showing the maximum of tolerance for the various crops; as already stated, many alkali spots were examined that gave no definite results, and are therefore omitted from the statement.

It should be said that the limits of tolerance thus far shown are probably too low for many of the cultures and that further investigation will without doubt greatly enlarge these limits on the part of some of the crops enumerated.

GRAIN.

Observations have been made for a number of years on the grains of the experiment station at Tulare, and it has been proven that they will grow in alkali soils containing 26,000 pounds of salt per acre in a depth

of four feet where there is an absence of sufficient carbonate of soda to corrode the tender crowns of the roots.

Alkali Salts in Grain Lands.

	Condition.	Per Cent in Soil.				Pounds per Acre: 4 ft. depth.			
		Sulfates	Carbonate	Chlorid	Total	Sulfates (Glauber Salt)	Carbonate (Salsoda)	Chlorid (Common Salt)	Total Salts
WHEAT—									
Tulare—Russian, Plot 12	3 feet high	.064	.006	.007	.077	10,240	1,000	1,120	12,360
	20 in. high	.095	.009	.004	.108	15,120	1,480	680	17,280
	6 in. high	.213	.023	.017	.253	34,120	3,640	2,680	40,440
Plot 16	Good	.089	.005	.007	.101	14,160	720	1,160	16,040
	Medium	.126	.001	.025	.152	20,120	200	3,920	24,240
	Very poor	.289	.002	.054	.345	46,160	360	8,680	55,200
Armona	Dead	.144	.026	.034	.204	23,040	4,180	5,360	32,580
GLUTEN WHEAT—									
Tulare	4 feet high	.027	.019	.001	.047	4,240	3,000	200	7,440
	Good	.131	.012	.009	.152	20,960	1,880	1,480	24,320
BARLEY—									
Tulare	4 feet high	.063	.074	.015	.152	10,720	12,170	2,630	25,520
Tulare (in 2 feet soil)	Yield 1 ton	.150	.028	.064	.242	12,020	2,200	5,100	19,320
Tulare	Dead	.061	.117	.020	.198	9,760	18,720	3,200	31,680
Hynes	Dead	.076	.020	.056	.152	12,160	3,200	8,960	24,320
RYE—									
Tulare		.061	.006	.011	.078	9,800	960	1,720	12,480

Wheat.—The Russian wheats, received from the U. S. Department of Agriculture, were planted in plot 12 of the Tulare substation. The rows extended across an alkali spot and the growths presented heights corresponding to the strength of alkali; that in the soil of strongest alkali being about six inches, that at the end of the rows where alkali was weak having a height of several feet. Samples of soil were taken at the two extremes and at a medium point, as shown in the table above. The gradation in size seems to follow a similar gradation in amount of carbonate of soda, in inverse order, the smaller the carbonate the higher the stalk of wheat, 1,480 pounds being about the limit of tolerance. The amount of common salt was rather small to influence the results with the Russian wheats, but on plot 16 with other varieties it seemed to be the chief agent, the grain suffering more and more as the salt increased, a medium height occurring where there was 3,920 pounds per acre in four feet depth. The plot on which this wheat was planted is quite sandy and deep, with a thin incrustation of alkali on the surface, especially where the grain was poorest.

On plot 16, and in fact on all of the northwest corner of the station which is given to wheat, the ground was covered with a thick and white crust of alkali salts, even where the grain was several feet in height. The soil here is more of a loamy nature than that of plot 12, and was

Not reclaimed. Partly reclaimed. Fully reclaimed.

FIG. 10. Grain on alkali land reclaimed and partly reclaimed by application of gypsum.

once a black alkali spot utterly bare of vegetation, but has been reclaimed by applications of gypsum.

The sample from Armona, Kings County, is from land once included in Tulare Lake region, but long left dry by the drying-up of the lake. Here the wheat died in presence of 4,180 pounds (.026 per cent) of carbonate of soda and 5,360 pounds (.034 per cent) of common salt per acre in four feet, each being above the probable limits of tolerance.

From the results thus far obtained we would judge that wheat should do well in deep and loose soils having not more than 20,000 pounds of total alkali, of which there is not more than 1,200 pounds each of carbonate of soda and common salt per acre in four feet depth.

Barley.—The fact is shown in the table that barley grew to a height of four feet in land containing more than 12,000 pounds (.028 per cent) of carbonate of soda per acre in four feet, and produced one ton of hay per acre in presence of more than 5,000 pounds (.064 per cent) of common salt. It is therefore better adapted to alkali land than is wheat. It was killed by 18,720 pounds of carbonate of soda, as would happen with most plants.

In total salts, estimating the weight of the soil per acre-foot at 4,000,000 pounds, we find for the land on which *barley* refused to grow the figure 31,680 pounds of total salts per acre, corresponding to 0.198 per cent; while for the land on which barley gave a full crop we find 25,520 pounds, equivalent to 0.152 per cent for the whole soil column of four feet. In the other case, where barley produced a ton per acre, the percentages are higher (.242 of total and .064 of common salt), but the alkali was in the upper two feet and not distributed through four feet, thus giving a smaller result when calculated in pounds per acre.

It thus appears that for barley the limits of tolerance lie between the above two figures, which might, of course, have been obtained equally well from an average sample of the 4-foot column by making a single analysis. It should be noted that in this case a full crop of barley was grown even when the alkali consisted of fully one half of the noxious carbonate of soda, proving that it is not necessary in every case to neutralize the *entire* amount of that salt by means of gypsum, which in the present case would have required about 9½ tons of gypsum per acre—a prohibitory expenditure.

Rye.—A fair test has not been given to rye as to its capabilities of withstanding alkali salts, for the amount found in the soil in which it was growing at the Tulare substation was very small. It, however, appears to be about like barley in its tolerance of alkali salts.

LEGUMES.

Both the natural growth of alkali lands and experimental tests seem to show that this entire family (peas, beans, clovers, etc.) are among

the more sensitive and least available wherever black alkali exists, while fairly tolerant of the white (neutral) salts. Apparently a very little salsoda suffices to destroy the tubercle-forming organisms that are so important a medium of nitrogen-nutrition in these plants. Alfalfa, with its hard, stout, and long taproot, seems to resist best of all these plants, excepting the melilots. As a general thing, taprooted plants, when once established, resist best, for the obvious reason that the main mass of their feeding roots reaches below the danger level. Another favoring condition, already alluded to, is heavy foliage and consequent shading of the ground; alfalfa happens to combine both of these advantages. There has been some difficulty in obtaining a full stand of alfalfa in the portion of the Chino tract containing from 4,000 to 6,000 pounds of alkali salts per acre; but once obtained it has done very well. The only other plant of this family that succeeds well on this land, and even (at Tulare) on soil considerably stronger (probably between 20,000 and 30,000 pounds), are the two melilots, *M. indica* and *alba;* the latter (the Bokhara clover) is a forage plant of no mean value in moist climates, but somewhat restricted in its use in California because of the very high aroma it develops, especially in alkali lands; so that stock will eat only limited amounts, best when intermixed with other forage, such as the saltbushes. The yellow melilot is highly recommended by the Arizona station as a greenmanure plant for winter growth; but in this State it is a summer-growing plant only, and is refused by stock. Very few plants belonging to this family are naturally found on alkali lands, and attempts to grow them, even where only glauber salt is present, have been but very moderately successful. The salts seem to retard or even prevent the formation of the tubercles useful for nitrogen absorption; and for most of the legumes the limit of full success seems to lie between 3,000 and 4,000 pounds to the acre.

Alfalfa.—Young alfalfa roots are very tender and sensitive to the corrosive action of carbonate of soda, and being confined to the upper foot or two of the soil are fully within its reach. But when the roots are older and have penetrated deeply into the soil, the root-crown has become more corky and hardened and less sensitive, so that they are enabled to withstand a far larger amount of the alkali.

From the many observations made at the substations and elsewhere we may place the tolerance of *young alfalfa* at about .015 per cent of carbonate of soda, .009 per cent of common salt, and .150 per cent of sulfate of soda in the upper two feet of soil; this is equivalent to 1,200 pounds of carbonate, 750 pounds of common salt, and 12,000 pounds of sulfate per acre in two feet. Old alfalfa did well in twice these amounts in the upper two feet.

The tolerance of alfalfa *after a good growth is secured* may be placed

at more than 2,000 pounds of carbonate of soda, 5,000 pounds of common salt, and 75,000 pounds of sulfate of soda per acre in four feet depth.

It is therefore very essential that prior to sowing alfalfa the alkali salts should be leached downward from the surface by thorough irrigation, until the plant is old enough to resist their attack by the hardening of its root-crown.

The importance of thoroughly washing the alkali deeply into the soil before the seed is planted, and keeping it there by proper means until the foliage of the plant shades the soil sufficiently to prevent the rise of moisture and alkali, is well illustrated in fields in the region of Bakersfield, where alfalfa is now growing in soils once heavily charged with alkali. From one of these fields samples of soil were taken by us where the alkali was supposed to be strongest beneath the alfalfa, and also from an adjoining untreated bare alkali spot which was said to represent conditions before alfalfa was planted. The results are given in pounds per acre in four feet depth:

	Sulfates.	Carbonate.	Common Salt.	Total Alkali.
Alkali spot before alfalfa was planted	60,120	720	175,840	236,680
Alfalfa field: alkali washed down	14,400	---	1,040	18,640

In the natural alkali soil the salts are distributed downward, somewhat evenly, except that there is in the surface foot nearly 140,000 pounds of common salt, while in the alfalfa field the alkali salts are chiefly below the second foot. A closer examination would doubtless have shown the main body of alkali to have been washed down to six feet from the surface, or even deeper.

Blue European Lupin.—The plot in which the lupins were grown has the greater part of its alkali within the upper two feet, while in that part where the lupins failed three-fourths of the common salt and the sulfates was held in the first foot itself. Both the common salt and sulfates seem to be responsible for the failure of the lupins, and it is clear that it can not withstand more than 5,000 pounds (.025 per cent) of the former per acre; of the carbonate of soda it will tolerate as much as and perhaps more than 3,000 pounds (.018 per cent) per acre.

Hairy Vetch.—This fodder and greenmanuring plant grew fairly well, reaching a height of about 14 inches and bloomed in land containing 2,400 pounds (.016 per cent) of carbonate of soda, 3,160 pounds (.020 per cent) of common salt, and 63,700 pounds (.398 per cent) of sulfate per acre in four feet depth. As with the lupins and the vegetables, we find that here, too, the alkali occurs chiefly in the upper two feet of the soil, the common salt especially being in the first foot.

The very large amount of sulfates tolerated would show that when

black alkali lands are neutralized with gypsum, the vetch will do fairly well, provided that common salt is not excessive. The limit of tolerance of the latter is a matter of doubt, for in the soil in which the vetch had a poor growth, there was present about 4,000 pounds (.025 per cent) of carbonate in addition to the 7,480 pounds (.047 per cent) of chlorid, and to either of these salts may have been due the bad effect. But in both of the soils examined the carbonate was chiefly in the second and third feet, and as its action is chiefly upon the tender root-crown at the surface of the soil, it would seem that the common salt was responsible for poor growth.

Bur Clover.—This clover was found growing luxuriantly in a small field adjoining the hot sulphur baths at Elsinore, in Riverside County. The soil received its water from a deep well, and was black from humus dissolved in the carbonate of soda of the alkali. An examination of the soil to thirty inches depth showed the remarkable toleration of 11,300 pounds (.113 per cent) of carbonate of soda per acre, thus giving it the rank of second in this regard among all the cultures examined. It doubtless is fully as tolerant as barley, which, aside from sorghum, heads the tolerance list of grasses thus far.

Fenugreek and Crimson Clover.—In the station at Chino these were killed in a soil having 1,520 pounds of sulfate of soda and 1,440 pounds of carbonate of soda (.012 per cent) per acre in three feet depth.

Sweet Peas.—In the region of Ross, Marin County, sweet peas died in a soil containing .037 per cent of common salt in the first foot. This is equivalent to nearly 1,500 pounds per acre.

OTHER FODDER PLANTS.

Australian Saltbush (*Atriplex semibaccata*).—This plant has been found growing well in very strong alkali land, in which the several salts were in greatest amount within two feet of the surface. As it ranks high as a fodder plant suitable for alkali soils, we give the distribution of the salts in the soil-column:

Alkali Soil Growing Australian Saltbush.

Depth.	Percentage in Soil.				Pounds per Acre.			
	Sulfates	Carbonate	Chlorid	Total	Sulfates	Carbonate	Common Salt	Total
First foot	2.055	.284	.121	2.460	82,200	11,360	4,840	98,406
Second foot	.634	.089	.111	.834	25,360	3,560	4,440	33,360
Third foot	.247	.042	.051	.340	9,880	1,680	2,040	13,600
Fourth foot	.205	.049	.030	.284	8,200	1,960	1,200	11,360
Total	3.141	.464	.313	3.918	125,640	18,560	12,520	156,720

These figures doubtless very nearly represent the maximum tolerance of the saltbush.

Very young plants have, however, suffered or languished in surface soils containing 9,000 pounds (.056 per cent) of carbonate of soda and 11,000 pounds (.070 per cent) of common salt, or a total of 31,000 pounds of alkali salts per acre; and have died when the soil was covered with an alkali crust containing 4.0 per cent of carbonate and 6.0 per cent of common salt. The plant came up easily from the seed in a soil containing 5,000 pounds (.032 per cent) of carbonate of soda and 3,000 pounds (.019 per cent) of common salt per acre.

Sorghum.—At the Tulare substation sorghum grows luxuriantly in a small tract having a large amount of alkali, the surface often being black from humus held by the carbonate of soda. Irrigation is used on the crop, and there is therefore more alkali at the surface than at the third and fourth feet, although the dense mass of the crop shades the soil quite effectually. An examination of the soil shows a higher amount of alkali salts than in the soil of any small culture thus far examined, viz.: 81,440 pounds per acre in four feet depth. This is more than one half of one per cent. Sorghum can easily tolerate as much as 10,000 pounds (.062 per cent) of carbonate of soda, the same of common salt, and 65,000 pounds (.40 per cent) of glauber salt per acre in four feet. At the time the examination was made, one half of the total glauber salt was in the upper foot, the greater part of the carbonate in the second and third feet, while the common salt was quite evenly distributed through the four feet.

ROOT CROPS AND VEGETABLES.

It seems to be generally true that root crops suffer in quality, however satisfactory may be the quantity harvested on lands rich in salts, and especially in chlorids (common salt). It was noted at the Tulare substation that the tubers of the artichoke were inclined to be "squashy" in the stronger alkali land, and failed to keep well; the same was true of potatoes, which were very watery; and also of turnips and carrots. It is a fact well known in Europe, that potatoes manured with kainit (chlorids of potassium and sodium) are unfit for the manufacture of starch, and are generally of inferior quality. But this is found not to be the case when, instead of the chlorids, the sulfate is used; hence the advice, often repeated by this Station, that farmers desiring to use potash fertilizers should call for the "high-grade sulfate" instead of the cheaper kainit, which adds to the injurious salts already so commonly present in California lowland soils.

Sugar Beets.—The *common beet* (including the mangel-wurzel) is known to succeed well on saline seashore lands, and it maintains its

reputation on alkali lands also. Being specially tolerant of common salt, it may be grown where other crops fail on this account; but the roots so grown are strongly charged with common salt, and have, as is well known, been used for the purpose of removing excess of the same from marsh lands. Such roots are wholly unfit for sugar-making.

It is quite otherwise with glauber salt (sodium sulfate); and as this is usually predominant in alkali lands, either before or after the gypsum treatment, this fact is of great importance, for it permits of the successful growing of the *sugar beet;* as has been abundantly proved at the Chino ranch, where land containing as much as 12,000 pounds of salts, mostly this compound, has yielded roots of very high grade both as to sugar percentage and purity.

The maximum of each salt tolerated by beets of good sugar and purity at Tulare and Oxnard (Station Bul. 169) is shown in the following table:

Depth.	Percentage in Soil.				Pounds per Acre.			
	Sulfates	Carbonates	Chlorid	Total Alkali	Sulfates	Carbonates	Chlorid	Total Alkali
Tulare—								
First foot	.752	.003	.028	.756	29,000	120	1,120	30,240
Second foot	.337	.042	.009	.388	13,480	1,680	360	15,520
Total in 2 feet	.531	.022	.019	.572	42,480	1,800	1,480	45,760
Total in 4 feet	.304	.025	.012	.341	48,560	4,000	1,920	54,480
Oxnard—								
First foot	.1980	.0084	.1120	.3184	7,920	320	4,480	12,720
Second foot	.0269	.0041	.0930	.1240	1,080	160	3,720	4,960
Third foot	.0196	.0034	.0930	.1160	780	120	3,720	4,620
Total in 2 feet	.1124	.0062	.1025	.2211	9,000	480	8,200	17,680
Total in 3 feet	.0815	.0053	.0993	.1861	9,780	600	11,920	22,300

It would seem, then, that in the absence of carbonate of soda, sugar beets will tolerate as much as 8,000 pounds of common salt per acre in two feet depth. In Europe .25 per cent per foot (10,000 pounds per acre) is considered the extreme limit in which workable beets can be obtained, and .20 per cent, or 8,000 pounds, is quite unobjectionable.

Carrots.—In the tule marshes of the Sacramento River at Rio Vista, Solano County, carrots are said to have grown well on a soil which was found to contain .139 per cent (11,120 pounds per acre) of common salt in the upper two feet, while in another spot of good carrots there was .260 per cent of common salt in the upper foot, which is equivalent to 10,400 pounds per acre. There was no carbonate of soda in either soil.

At the Tulare substation, in a plot having .223 per cent of sulfates (17,800 pounds per acre), .012 of carbonate of soda (960 pounds per acre), and .020 of common salt (1,560 pounds per acre) the plant grew well and its tubers had a length of about ten inches, but they had a diameter of only about three fourths of an inch.

Potatoes.—In the reclaimed tule-marsh lands of Victoria Island, in the region of Stockton, potatoes form a prominent crop, and examination of the soils shows that the crop can tolerate a large amount of common salt, as shown in this table:

Depth.	Percentage in Soil.				Pounds per Acre.			
	Sulfates	Carbonate	Chlorid	Total Alkali	Sulfates	Carbonate of Soda	Common Salt	Total Alkali
First foot	2.013		.285	2.298	20,130	None.	2,850	22,980
Second foot	.566		.074	.640	5,660		740	6,400
Third foot	.268		.148	.416	2,680		1,480	4,160
Fourth foot	.406		.074	.480	4,060		740	4,800
Total	.813		.145	.958	32,530		5,810	38,340

The maximum of common salt in the upper three feet was .169 per cent, or an average of 5,000 pounds per acre. In the fourth foot there was an additional 740 pounds, making a total of about 5,800 pounds in the four feet. The effect of so much common salt on the starch of the potato has not been ascertained in California, but is elsewhere understood to be unfavorable.

Onions.—Onions also do well on the reclaimed tule-marshes, even in the presence of as much as 3,000 pounds of common salt in the upper foot of soil, as was noted in the land around Rio Vista and on Victoria Island. They would tolerate doubtless much more than this.

Celery.—The celery fields in the alluvial lands around Santa Ana furnish good examples of the effects of alkali salts, except that no carbonate of soda was found in the samples kindly sent by Mr. Cole from spots where the plant was growing well and where the plant died. The results show that celery will easily tolerate as much as 10,000 pounds of common salt per acre, but is killed by 30,000 pounds. It is killed by 2,000 pounds of carbonate of soda.

Spinach and English Broad Bean.—The vegetables were grown at Tulare on very strong alkali soils and were almost complete failures. A few scattering plants appeared where the carbonate of soda was only 2,000 pounds per acre and chiefly below the first foot, but they reached

a height of only a few inches. The amount of common salt was about 9,000 pounds per acre.

Asparagus is another crop which bears considerable amounts of common salt as well as of glauber salt; but not of salsoda, which must first be transformed by the use of gypsum.

Rhubarb was a conspicuous failure in even the weak alkali lands of the Chino tract.

GRASSES, TEXTILE PLANTS, AND WEEDS.

Grasses.—Summarizing the data given in former publications we have the following groupings of maximum amounts in the surface foot per acre in which the true grasses have thus far been found to do well:

Grasses Growing in Alkali Soils. Depth one foot.

CARBONATE OF SODA.

3,300 lbs. per acre:	Japanese Wheat Grass, Barley.
2,500 to 3,000 lbs. per acre:	Awnless Brome Grass, Schrader's Brome Grass, Sheep Fescue, Tall Fescue.
2,000 to 2,500 lbs. per acre:	Egyptian Millet, Hard Fescue, Many-Flowered Paspalum, English Ray Grass, Rough-Stalked Meadow and Orchard Grass.
1,000 to 2,000 lbs. per acre:	Bearded Darnel, Blue Grass, Foxtail, and Alfileria.
600 to 1,000 lbs. per acre:	Meadow Fescue, Many-Flowered Millet, Meadow Soft Grass, Italian Ray Grass.

COMMON SALT.

7,040 lbs. per acre:	Barley.
3,000 lbs. per acre:	Japanese Wheat Grass, Foxtail, and Alfileria.
1,500 lbs. per acre:	Schrader's Brome Grass.
900 lbs. per acre:	Awnless Brome Grass, Sheep Fescue, Tall Fescue.
250 to 500 lbs. per acre:	Many-Flowered Millet, Italian Ray Grass, English Ray Grass, Bearded Darnel, Orchard Grass.

Textile Plants.—Japanese hemp seemed to have a hard struggle with the alkali while young, but at the end of the season stood eight feet high. The ramie plant, also, will bear moderately strong alkali, apparently somewhat over 12,000 pounds per acre. Flax has not been tested in cultivation; but its wide distribution all over the States of Oregon and Washington would seem to indicate that it is not very sensitive. Another textile plant, the Indian mallow (*Abutilon avicennae*), was found to fail on the Chino alkali soil.

Weeds.—Like the legumes, wild plants of the *mustard* family are rare on alkali lands; and correspondingly, the cultivated mustard, kale, rape, etc., fail even on land quite weak in alkali. Their limit of tolerance seems to lie near 4,000 to 5,000 pounds per acre of even white salts.

Several of the hardiest of the native "alkali weeds" belong to the *sunflower* family, and the common wild sunflowers (*Helianthus californicus* and *H. annuus*) are common on lands pretty strongly alkaline.

Correspondingly, the "Jerusalem artichoke," itself a sunflower, is among the available crops on moderately strong alkali soils; and so, doubtless, are other members of the same relationship not yet tested, such as the true artichoke, salsify, etc. Chicory, belonging to the same family, yielded roots at the rate of 12 tons per acre, on land on the Chino tract containing about 8,000 pounds of salts per acre.

GRAPEVINES.

The *Vitis vinifera* is quite tolerant of white or neutral alkali salts, and will resist even a moderate amount of the black so long as no hardpan is allowed to form. At the Tulare substation in 1899 it was found that grapevines did well in sandy land containing 35,230 pounds (.220 per cent) of alkali salts per acre in four feet depth, of which one half was glauber salt, 9,640 pounds carbonate of soda, 7,550 pounds common salt, and 750 pounds nitrate of soda. They were badly distressed where, of a total of 37,020 pounds (.282 per cent) of alkali salts, 25,620 pounds (.160 per cent) was carbonate of soda; while where the vines had died out, there was found a total of 73,930 pounds (.412 per cent), with 37,280 pounds (.233 per cent) of carbonate in a depth of four feet. The European vine, then, is considerably more resistant of alkali, even in its worst (black) form, than barley and rye; and it seems likely that the native grapevines of the Pacific Coast, *Californica* and *Arizonica*, would resist even better; a point still under experiment.

Experience, however, has shown that vines rapidly succumb when by excessive irrigation the bottom water is allowed to rise, increasing the amount of alkali salts near the surface and shallowing the soil at their disposal. Such over-irrigation has been a fruitful cause of injury to vineyards in the Fresno region, and would doubtless, if practiced, kill most of the vines at Tulare substation which are now flourishing. In such cases sometimes the formation of hardpan is followed by that of a concentrated alkaline solution above it, strong enough to corrode the roots themselves, and not only killing the vines, but rendering the land unfit for any agricultural use whatsoever. The swamping of alkali lands, whether of the white or black kind, is not only fatal to their present productiveness, but, on account of the strong chemical action thus induced, greatly jeopardizes their future usefulness. Many costly investments in orchards and vineyards have thus been rendered unproductive, or have even become a total loss.

Grape Varieties.—A large part of the Tulare substation tract is occupied by grapes representing about one hundred and fifty varieties. Alkali spots have appeared here and there (by rise from below through use of irrigation water), and in several instances the salts have seriously affected the vines. The results of the examination of the soils forcibly illustrate the fact that the susceptibility of the vine varies according

to variety, and that while some are tolerant of very large amounts of carbonate of soda and common salt, others succumb to the effect of far less of each.

Alkali in Vineyard Soils.

Grapevines.	Condition.	Percentage in Soil.				Pounds per Acre: 4 ft. depth.			
		Sulfates	Carbonate	Chlorid	Total	Sulfates (Glauber Salt)	Carbonate (Salsoda)	Chlorid (Common Salt)	Total Salts
Persian	Lived	.144	.063	.077	.284	17,290	7,550	9,640	34,480
Persian	Barely lived	.072	.214	.005	.291	8,670	25,620	640	34,930
Persian (3 feet)	Died	.205	.311	.091	.607	24,640	37,280	10,890	72,810
Sauvignon vert	Thrifty	.255	.003	.028	.286	40,800	480	4,480	45,760
Chasselas	Thrifty	.247	.005	.031	.283	39,520	800	4,960	45,280
Boal de Madeira	Thrifty	.188	.004	.028	.220	30,080	640	3,680	34,400
Mission Grape	Thrifty	.160	.030	.006	.196	25,640	4,760	960	31,360
Mission Grape	Not growing	.416	.010	.006	.432	66,520	1,560	920	69,000
Trousseau	Thrifty	.170	.007	.019	.196	27,200	1,120	3,040	31,360
Verdal	Thrifty	.160	.003	.023	.186	25,600	480	3,680	29,760
Teinturier mâle	Thrifty	.150	.003	.029	.182	24,000	480	4,640	29,120
Thompson Seedless	Thrifty	.134	.003	.013	.150	21,480	520	2,040	24,040
Burger	Thrifty	.120	.005	.090	.215	19,200	800	1,440	21,440
Meunier	Thrifty	.094	.010	.006	.110	15,040	1,600	960	17,600
Meunier	Suffered	.209	.007	.012	.228	33,440	1,120	1,920	36,480
Meunier	Died	.207	.007	.018	.232	33,120	1,120	2,880	37,120
Flame Tokay	Thrifty	.070	.045	.004	.119	11,200	5,560	600	17,360
Pedro Jimenes	Thrifty	.067	.023	.004	.094	10,680	3,600	600	14,880
Pedro Jimenes	Not growing	.110	.029	.006	.145	17,600	4,640	960	23,200
Negro	Thrifty	.081	.012		.093	12,960	1,920		14,880
Negro	Not growing	.206	.022	.005	.233	33,000	3,480	800	37,280

Of the above fourteen varieties of grapes the Persian withstands the effects of alkali the best, especially of carbonate of soda and common salt. There seems but little doubt that it would flourish in soils containing one tenth of one per cent of common salt, or an equivalent of 16,000 pounds per acre in four feet. The tolerance for carbonate of soda is great, for in the presence of more than two tenths of one per cent, or 25,600 pounds per acre, it managed to keep alive, thus indicating a true tolerance of probably 15,000 or perhaps 20,000 pounds per acre in four feet.

For other varieties the limits vary greatly, some being more sensitive to the several salts than others. The Sauvignon vert and Chasselas appear to be more tolerant of glauber salt and common salt than were other varieties, for they made a fine growth in the presence of about 40,000 pounds of sulfate and 5,000 pounds of common salt per acre in four feet. The Teinturier mâle would probably be their equal, for its amount of common salt was nearly the same.

The amount of carbonate of soda (black alkali) which the grape is able to withstand was in a few cases fairly well shown, especially where the common salt was low. Thus the Flame Tokay grew well in soil with 5,500 pounds of carbonate, and the Mission in the presence of 4,700 pounds.

The Meunier is very sensitive to alkali salts and succumbed to small amounts of carbonate and common salt combined with 33,000 pounds of sulfate, which was less than that in which many other varieties grew well. As a rule, grapevines seem to easily withstand 30,000 pounds of sulfate, and 5,000 pounds of carbonate and common salt each.

Note on the Effect of Alkali Salts upon the Growth of Grapevines and on the Composition of Grapes.

By A. M. dal Piaz.

The injurious effect of strong alkali salts upon fruits in general is well known; grapevines are no exception, for strong alkali will kill them and weaker alkali affects them proportional to its strength and composition. The effect of alkali upon the vine and its product is a matter of economic interest, and an investigation on this subject was begun by the writer upon vines at the Tulare substation in 1900, and the results are here briefly presented; analyses of the alkali soils in which the vines were growing were made in the Station laboratory by Mr. Snow.

The vines of the Burger, Sauvignon vert, and Trousseau were growing partly in weak and partly in strong alkali soils. The grapes of each variety did not show any marked difference in size, excepting where growing in strong alkali; but the vines themselves were there considerably shorter in growth, and therefore the bunches and berries were smaller and more advanced in maturity.

The Meunier is growing about an alkali spot, partly on weak alkali and showing a healthy growth, partly on stronger alkali and showing a shorter growth, and were killed on still stronger alkali. The following table gives the composition of these alkali soils, to which is added the results of examination of the sugar, acid, ash, and tannin in the grapes grown respectively on the weak and the strong alkali:

Pounds of Alkali Salts per Acre in Four Feet Depth.

	Sauvignon Vert.		Burger.		Trousseau.		Meunier.		
	Weak Alkali.	Strong Alkali.	Weak Alkali.	Strong Alkali.	Weak Alkali.	Strong Alkali.	Weak Alkali.	Strong Alkali.	Strong Alkali.
Sulfates	21,760	40,800	19,200	21,280	20,480	27,200	15,040	33,440	33,120
Carbonate	1,280	480	800	640	480	1,120	1,600	1,120	1,120
Chlorid	4,480	4,480	1,440	1,440	4,000	3,040	960	1,920	2,880
Total	25,520	45,760	21,440	23,360	24,960	31,360	17,600	36,480	37,120

Proximate Composition of Grapes: August 24, 1900.

Sugar %	26.39	24.43	20.24	20.60	25.75	24.64	26.86	24.53	
Acid %	.38	.65	.71	.59	.47	.50	.45	.50	Vines
Ash %	.28	.37	.33	.33	.49	.36	.36	.40	killed.
Tannin %					.147	.155	.159	.167	

The four grape varieties of the above table, grown on weak and strong alkali soils, show differences in growth and grape composition remarkably well. The sugar content seems to have throughout the tendency of decreasing with increasing strength of the alkali salts; this is shown by the varieties of Sauvignon vert, Trousseau, and Meunier. The Burger does not show this, because of the nearly equal strength of alkali in both soils.

The total acidity of the grapes seems to be less influenced by variations in strength of alkali; three of the varieties show an increase with increased alkali. This increase of total acidity and decrease of sugar content in strong alkali soils is doubtless caused by the diminished vigor and poor growth of the vines in such soils.

The analysis of the red wine varieties, Trousseau and Meunier, indicates a slight rise of tannin with increasing strength of alkali in the soils; this increase is, however, too small for drawing any final conclusions.

The above results seem to indicate some important facts worthy of being made known. First of all, the quality of wine grapes of the Tulare region does not decrease with increasing strength of alkali in the soil, at least up to a certain limit of total salts. The increase of total acidity of the grapes grown in stronger alkali is of special value in the making of sound wines in similar localities, while the decrease of sugar content secures at the same time a wine not too alcoholic. The practical wine-making experiments with Tulare grapes, undertaken by the Agricultural Experiment Station, have indicated this fact: they have shown that sound, light table-wines, excellent for blending purposes, or as light neutral wines for consumption, could be made of grapes grown on such alkali soils.

The growing of raisin grapes in strong alkali soils can not be recommended, as the tendency of the sugar content to decrease with increasing alkali results in the production of an inferior raisin.

ORCHARD CROPS.

It will be seen that the list in the table below comprises the chief orchard crops of California; and while most of them are represented in their extremes of good and poor growths, there are a few which could only be found in a state of good growth, and in what seemed to be strong alkali.

Alkali in Soils of Orchards.

Trees.	Condition.	Percentage in Soil.				Pounds per Acre: 4 ft. depth.			
		Sulfates	Carbonate	Chlorid	Total	Sulfates (Glauber Salt)	Carbonate (Salsoda)	Chlorid (Common Salt)	Total Alkali
Almonds—									
Tulare	Good	.142	.009	.015	.166	22,720	1,440	2,400	26,560
Apples—									
Tulare—Red Bietigheimer	Good	.089	.004	.008	.101	14,240	640	1,240	16,120
Duchess	Poor	.117	.008	.021	.146	18,760	1,200	3,320	23,280
Jonathan	Poor	.029	.005	.007	.041	6,840	1,080	1,720	9,640
Apricots—									
Tulare	Good	054	003	.006	.063	8,640	480	960	10,080
Tulare	Affected	.214	.011	.021	.246	34,240	1,760	3,260	39,260
Figs—									
Tulare—Osburn's Prolific	Good	.153	.007	.005	.165	24,480	1,120	800	26,400
California Black	Good	.068	.005	.001	.074	10,880	760	160	11,800
Lemons—									
La Mirada	Good	.028	.003	.005	.036	4,480	480	800	5,760
La Mirada	Stunted	.032	.003	.009	.044	5,120	480	1,440	7,040
La Mirada	Dead	.039	.007	.012	.058	6,240	1,120	1,920	9,280
Olives—									
Tulare—Nigerina	Good	.192	.018	.042	.252	30,640	2,880	6,640	40,160
Regalis	Good	.126	.017	.021	.164	20,160	2,640	3,360	26,160
La Mirada	Good	.025	.015	.014	.054	4,000	2,400	2,240	8,640
La Mirada	Stunted	.271	.029	.074	.374	43,360	4,640	11,840	59,840
Kern City	5 feet	.245	.010	.152	.407	49,000	2,000	30,400	81,400
Oranges—									
Tulare	Fair	.062	.024	.021	.107	9,840	3,840	3,360	17,040
Chino	Good	.155	.012	.015	.182	18,600	1,440	1,800	21,840
Corona	Fair	.018	.008	.002	.028	2,920	1,280	360	4,560
Corona	Poor	.028	.013	.011	.052	4,520	2,000	1,800	8,320
Corona	Poor	.029	010	.015	.054	4,720	1,680	2,520	8,920
Peaches—									
Tulare	Best	.060	.004	.006	.070	9,600	680	1,000	11,280
Tulare	Poor	.084	.007	.015	.106	13,400	1,160	2,440	17,000
Hanford	Poor	.088	.002	.070	.160	14,080	320	11,200	25,600
Pears—									
Tulare	Best	.111	.011	.009	.131	17,800	1,760	1,360	20,920
Tulare	Poor	.239	.013	.009	.261	38,280	2,080	1,360	41,720
Plums—									
Tulare	Very poor	.140	.011	.014	.165	22,360	1,760	2,120	26,240
Prunes on Myrobalan—									
Tulare	Good	.058	.009	.008	.075	9,240	1,360	1,200	11,800
Mulberry—									
Tulare	Good	.021	.001	.014	.036	3,360	160	2,240	5,760

Almonds.—The almond trees of the Tulare substation are isolated from the other orchard growths and were all in a healthy condition and loaded with fruit. No trees have been found whose poor condition could be attributed to alkali; hence, the greatest limit of tolerance in the almond has as yet not been ascertained, but is clearly above 2,000 pounds of carbonate of soda and 3,000 pounds of common salt per acre four feet deep.

Apples.—The tree is quite sensitive to alkali salts, and their effect on the foliage of the tree was very marked, as is shown in the accompanying illustration (Fig. 11). The newer limbs of the tree appear as

Red Bietigheimer.
In good condition.

Duchess of Oldenburg.
Somewhat affected.

Jonathan.
Badly affected.

FIG. 11. APPLE TREES IN ALKALI GROUND.

canes with a tuft of leaves at the upper end, instead of being covered with foliage throughout, as is also shown in the photograph. Samples of soil were taken to the depth of four feet under the Duchess of Oldenburg, which was in very poor condition, with no fruit, and whose top was losing its leaves; the Jonathan, also very poor, and the Red Bietigheimer, which was in excellent condition. The results of the examination make it clear that while the apple will tolerate the presence of 14,000 pounds of sulfates, 650 of carbonate of soda, and 1,200 of common salt, it is injured by 1,200 pounds of carbonate and 3,000 pounds of common salt per acre distributed through four feet depth. The Jonathan seems to be more sensitive than the Duchess.

Apricots.—The trees selected as representing the best and the worst condition respectively were grown upon their own stock. The differences between the two were very marked, in the greater height and full foliage, large leaves, and vigorous growth in the one, and the thinner foliage, smaller and blighted leaves, new leaves in clusters at end of limb, and evident poor health in the other; some twigs had lost their leaves entirely. The accompanying photograph (Fig. 12) shows these effects. The results of the examination of the respective soils show that while the total alkali and that of each salt are greater in the soil of the poor tree, and that to either of these might be attributed the trouble, it is more than likely that either the sulfate or the common salt is the true cause; for their amounts are excessive, while that of the carbonate is lower than what is tolerated by most cultures.

Figs.—The tree easily tolerated as much as 25,000 pounds of glauber salt and 1,100 pounds of carbonate of soda per acre in four feet.

Lemons.—The lemon seems to be the least tolerant of all of the fruit trees, for it was apparently stunted by only 1,440 pounds of common salt per acre distributed through four feet depth, and was killed by 1,900 pounds combined with 1,900 pounds of carbonate of soda. Its endurance of carbonate of soda has not been ascertained.

Oranges.—From the culture experiments at Tulare substation it would seem that oranges do fairly well in the presence of 3,840 pounds of carbonate and 3,360 pounds of common salt per acre in four feet depth, or a total of 17,040 pounds of alkali. The examinations at Corona seem to contradict this, for there the trees suffered in 1,680 pounds of carbonate and 2,500 pounds of common salt. The explanation is that the conditions surrounding the trees were different, for at Tulare a detailed examination shows that the salts were distributed through the four feet of soil quite evenly, while at Corona the common salt was all contained in the first two feet. Then, too, at Tulare the

Good.

Yielding to alkali.

FIG. 12. APRICOT TREES.

roots of the tree were by proper culture encouraged to send their feeding roots to a depth of seven or eight feet below the surface, while at Corona the system of shallow furrow-irrigation so much practiced in southern California had compelled the roots to remain within a short distance of the surface of the soil to secure necessary moisture, and hence the salt concentrated near the surface could act with greater energy.

Thus is emphasized the importance of the oft-repeated injunction to so use irrigation water and cultivation as to permit the roots of trees to follow their natural tendency of penetrating deeply into the soil. Had the salts in the Corona soils been distributed through a greater depth the trees would doubtless have withstood the effects of the alkali much longer. In fact, since the publication of the Station Report of 1898, the orchardists of Corona have very greatly improved their groves by this treatment and the use of pure water; and the particular orchard there shown as typical of the effects of alkali has now recovered its vigor and foliage.

Olives.—The olive trees of the Tulare substation were all in good condition when visited, though some stood in soils quite highly charged with alkali salts. Of those represented in the table the Præcox was in a sandy soil, while the Regalis and Nigerina were in loams. Samples of soil were also sent to this office from an olive orchard near La Mirada, Los Angeles County, by the manager. One lot of samples was from the high part of the orchard, where the trees were large and healthy; the other lot was from lower land, where the trees were six years old, but stunted (four feet high); the same treatment had been given the trees in both cases. Another series of samples was sent by the manager of an olive orchard near Kern City, Kern County, in which the trees were suffering. The results of examination are shown in the table.

The olive tree is clearly immune to as much as 3,000 pounds of carbonate of soda (black alkali) and 30,000 pounds of glauber salt per acre in four feet, and the limit of tolerance will probably be found to be much above those figures.

The tolerance for common salt is above 6,000 pounds per acre in four feet, for the Nigerina did well in about that amount. At La Mirada the trees were stunted in presence of 11,800 pounds, and killed in an orchard near Kern City where there was 19,500 pounds in four feet depth and 30,400 pounds in five feet. At Kern City, however, the greater part of the alkali was contained in the soil below a depth of two feet, and had the examination gone deeper than five feet there would doubtless have been found in all about 50,000 pounds of common salt in a total of over 100,000 of alkali salts.

The following method of planting the trees adopted by the owner of the latter orchard has enabled them to secure a good growth before the roots felt the effects of the alkali, and illustrates the importance with some cultures of forcing the alkali down to quite a depth by the use of plenty of water and allowing the plant to secure a foothold:

The holes for the trees are made three feet deep and as wide, several months before planting; near planting time they are partially filled with good soil and filled with water. When the water has seeped down, the holes are filled with top soil and the trees planted. The alkali is thus washed beyond the depth of the roots. There is hardly a doubt but that if there had not been such an enormous amount of alkali in the lower four or five feet the trees would have successfully resisted its effect on the roots.

Peaches.—The trees at the Tulare substation were in part in fairly good and in part in poor condition, and samples of soils were taken from the best representatives of each. Both were on peach stock, and the difference in appearance was in smaller leaves and general unhealthy growth, due to either the common salt or carbonate as shown in the table.

From the region of Hanford, Kings County, peach trees were reported as being in bad condition. The examination of this soil shows the presence of an enormous amount (11,200 pounds) of common salt in the four feet, to which doubtless the dying of the trees must be attributed.

The results obtained at Tulare make it probable that the limits of alkali tolerated by peach trees may be placed at 10,000 pounds of sulfates, 750 of carbonate, and 1,200 of common salt per acre in four feet depth.

Pears.—The effect of alkali upon the pear was noticed only in the orchard of the Tulare substation, where quite a large block of land is given to its culture. Through the central part of this lies a belt of alkali which has seriously injured some of the trees, the leaves turning yellow or blackening at the tips, and others being killed. On either side of this belt the trees are in good condition and bear well. Samples of soil were taken under LeConte and Keiffer trees which were yielding to alkali, showing the yellow leaves with blackened tips; they had no fruit.

The samples from the "best trees" are from the northern part of the pear block. The trees are Kennedy varieties and were planted long before the alkali had encroached on them; so that their roots have escaped attack, although the amount of alkali is greater than under the other trees.

The results would seem to show that while the pear can tolerate as much as 1,400 pounds of common salt and 1,800 pounds of carbonate per acre in four feet, it is seriously affected by 38,000 pounds of the

sulfate, for it is hardly possible that an addition of 320 pounds of carbonate in the four feet per acre would produce the damage.

In another locality the trees were killed in land whose surface soil contained 4,600 pounds of carbonate and 18,000 pounds of common salt in a total of 62,000 pounds.

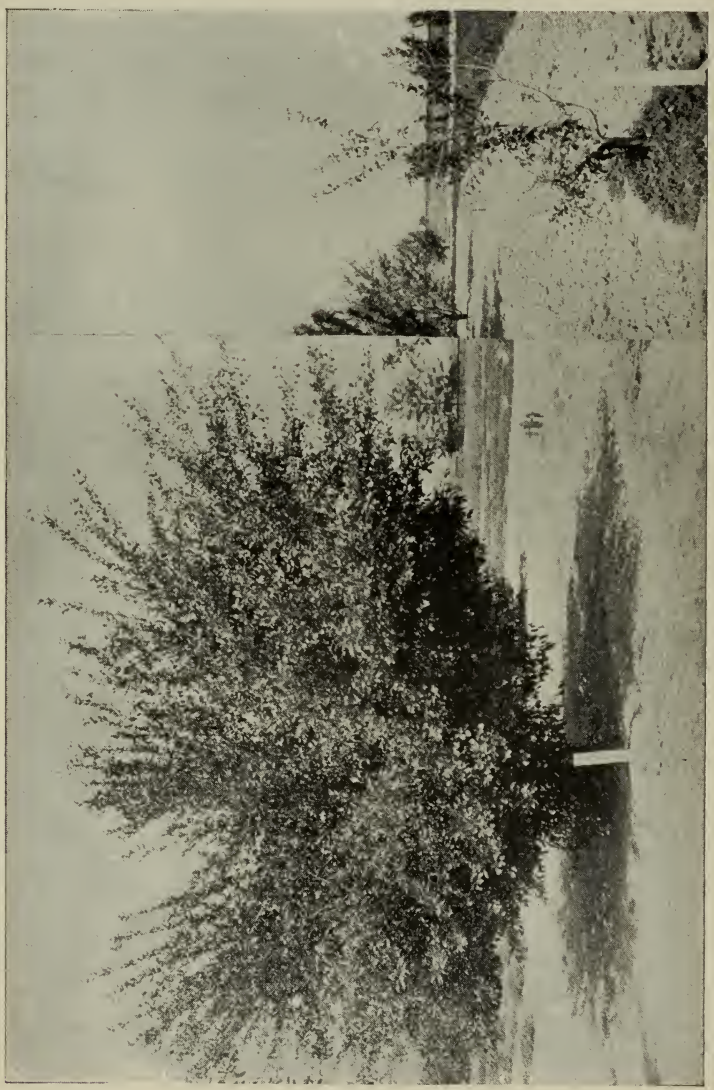

FIG. 13. PRUNE AND PLUM IN ALKALI SOIL.

Plums.—The Robe de Sergent plum at the Tulare substation is on its own stock and suffering very severely from alkali, as shown in the photograph on Fig. 13. The tree was dwarfed, and the limbs were losing their leaves. The amount of alkali in this case was not large,

only 26,240 pounds, and amounts of the carbonate and common salt were also comparatively small. This plum, therefore, is one of the most sensitive of trees to the effects of alkali salts.

Prunes.—Prune trees, if grown on Myrobalan stock, should be highly tolerant of alkali salts, for that stock is a native of Asia Minor, where alkali abounds. We have thus far been unable to secure samples of soil where the trees showed the effect of alkali. At the Tulare substation the amount in their soils was only about 12,000 pounds per acre in four feet, and of this only 1,360 was of carbonate and 1,200 of common salt. It is said that at Hanford, Kings County, the prune flourishes in alkali soils where the peach is severely affected; we may therefore place the power of tolerance at quite high figures for common salt at least. If it be true that this fruit tree can withstand a very large amount of common salt it will prove of great value in alkali regions, for the carbonate of soda part of alkali can easily be neutralized by gypsum.

Walnuts.—Samples of soil were sent from an orchard near Anaheim, Orange County, in which "walnut trees have been planted, but they soon died and the roots rotted very quickly, while outside of this spot they do exceptionally well." The examination of the samples showed the presence of 18,000 pounds of common salt and about the same amount of sulfates per acre in four feet depth.

TIMBER AND SHADE TREES.

Of trees suitable for alkali lands, two native ones call for mention. One is the California white or valley oak (*Quercus lobata*), which forms a dense forest of large trees on the delta lands of the Kaweah River in California, and is found scatteringly all over the San Joaquin Valley. Unfortunately, this tree does not supply timber valuable for aught but firewood or fence posts, being quite brittle. The native *cottonwoods,* while somewhat retarded and dwarfed in their growth in strong alkali, are quite tolerant of the white salts, especially of glauber salt.

Of other trees, the oriental plane, or sycamore, and the black locust, have proved the most resistant in the alkali lands of the San Joaquin Valley; and the former being a very desirable shade tree, it should be widely used throughout the regions where alkali prevails more or less. The ailantus is about equally resistant, and but for the evil odor of its flowers, deserves strong commendation. Of the eucalypts, the narrow-leaved *Eucalyptus amygdalina* (one of the "red gums") seems to be least sensitive, and in some cases has grown as rapidly as anywhere.

The *E. rostrata,* as well as the pink-flowered variety of *E. sideroxylon,* are now doing about as well as the *amygdalina* at Tulare, where at first they seemed to suffer. The common blue gum, *E. globulus,* is much more sensitive.

Of the acacias, the tall-growing *A. melanoxylon* ("black acacia") resists pretty strong alkali, even on stiff soil; as can be seen at Tulare and Bakersfield, where there are trees nearly two feet in diameter. The beautiful *A. lophantha* (Albizzia) has in plantings made along the San Joaquin Valley Railroad shown considerable resistance, likewise; but it is quite sensitive to frost.

One of the "Australian pines, *Casuarina equisetifolia,*" was transplanted experimentally on station grounds of the Valley Railroad from the Chico forestry substation, and a number are growing very well in alkali lands. This tree is credited by Maiden with being tolerant of "saline soil." Doubtless many others of the *Casuarina* tribe will be found similarly resistant.

Of *Eastern trees,* the elms have done fairly well, but the tulip tree, the linden, the English oak, and most other trees of the Atlantic States, become stunted. Among those doing fairly well is the honey locust; but its thorns and imperfect shade render it not very desirable.

The California maple (*Acer macrophyllum*) and box elder (*Negundo californica*) have done fairly well in the lighter alkali lands at Tulare.

A most remarkably alkali-resistant shrub or small tree is the pretty *Koelreuteria paniculata,* which at Tulare is growing in some of the strongest alkali soil of the tract (.062 per cent or about 10,000 pounds in four feet per acre). Unfortunately it is available mainly for ornamental purposes; its wood, while small, is very hard and makes excellent fuel.

A number of *Washingtonia palms* are growing along the border of the Tulare station tract and county road, in soils containing about .097 per cent or 15,000 pounds of alkali salts per acre. The palms look well and none of them seem to have been affected by alkali.

A large *date palm* is growing in a sandy alkali soil at the Tulare substation and is not at all affected by the two hundredths of one per cent (2,800 pounds per acre) of carbonate of soda present. It will clearly tolerate a larger amount. Only a trace of common salt was found in the soil.

The carbonate of soda around the roots of a large *Oriental sycamore* tree is comparatively small (.020 per cent or 3,200 pounds per acre), but common salt is present to the extent of more than one tenth of one per cent, which gives the enormous amount of 20,000 pounds per acre in four feet depth. It is clear, then, that in almost any alkali land reclaimed from carbonate of soda this tree will make good growth.

GENERAL SUMMARY OF RESULTS THUS FAR OBTAINED.

The following tables present in brief form, for comparison, the nearest approach to maximum tolerance of *each* of the salts of alkali thus far obtained for fruits and other cultures; giving, of course, the amounts in which each culture was growing and in good condition entirely unaffected by alkali. The cultures are arranged in the order of highest tolerance.

These results are of course only tentative, for in a great majority of cases future examinations will probably greatly raise the figures given in the tables.

Highest Amount of Alkali in Which Fruit Trees Were Found Unaffected.

Arranged from highest to lowest. Pounds per acre in four feet depth.

Sulfates (Glauber Salt).		Carbonate (Sal Soda).		Chlorid (Common Salt).		Total Alkali.	
Grapes	40,800	Grapes	7,550	Grapes	9,640	Grapes	45,760
Olives	30,640	Oranges	3,840	Olives	6,640	Olives	40,160
Figs	24,480	Olives	2,880	Oranges	3,360	Almonds	26,560
Almonds	22,720	Pears	1,760	Almonds	2,400	Figs	26,400
Oranges	18,600	Almonds	1,440	Mulberry	2,240	Oranges	21,840
Pears	17,800	Prunes	1,360	Pears	1,360	Pears	20,920
Apples	14,240	Figs	1,120	Apples	1,240	Apples	16,120
Peaches	9,600	Peaches	680	Prunes	1,200	Prunes	11,800
Prunes	9,240	Apples	640	Peaches	1,000	Peaches	11,280
Apricots	8,640	Apricots	480	Apricots	960	Apricots	10,080
Lemons	4,480	Lemons	480	Lemons	800	Lemons	5,760
Mulberry	3,360	Mulberry	160	Figs	800	Mulberry	5,760
Other Trees.							
Kölreuteria	51,040	Kölreuteria	9,920	Or. Sycamore	20,320	Kölreuteria	73,600
Eucal. am.	34,720	Or. Sycamore	3,200	Kölreuteria	12,640	Or. Sycamore	42,760
Or. Sycamore	19,240	Date Palms	2,800	Eucal. am.	2,960	Eucal. am.	40,400
Wash. Palms	13,040	Eucal. am.	2,720	Camph. Tree	1,420	Wash. Palms	15,280
Date Palms	5,500	Wash. Palms	1,200	Wash. Palms	1,040	Date Palms	8,320
Camph. Tree	5,280	Camph. Tree	320			Camph. Tree	7,020
Small Cultures.							
Saltbush	125,640	Saltbush	18,560	Modiola	40,860	Saltbush	156,720
Alfalfa, old	102,480	Barley	12,170	Saltbush	12,520	Alfalfa, old	110,320
Alfalfa, young	11,120	Bur Clover	11,300	Sugar Beet*	11,900	Alfalfa, young	13,120
Hairy Vetch	63,720	Sorghum	9,840	Sorghum	9,680	Sorghum	81,360
Sorghum	61,840	Radish	8,720	Celery	9,600	Hairy Vetch	69,360
Sunflower	52,640	Modiola	4,760	Potatoes	5,810	Radish	62,840
Radish	51,880	Sugar Beet	4,000	Onions	5,810	Sunflower	59,840
Sugar Beet	48,560	Gluten Wheat	3,000	Alfalfa, old	5,760	Sugar Beet*	54,480
Artichoke	38,720	Artichoke	2,760	Alfalfa, young	760	Modiola	52,420
Potatoes	32,530	Lupin	2,720	Sunflower	5,440	Artichoke	42,960
Onions	32,530	Hairy Vetch	2,480	Barley	5,100	Potatoes	38,340
Carrot	24,880	Alfalfa	2,360	Hairy Vetch	3,160	Onions	38,340
Gluten Wheat	20,960	Grasses	2,300	Lupin	3,040	Carrot	28,480
Wheat	15,120	Kaffir Corn	1,800	Carrot†	2,600	Barley	25,520
Barley	12,020	Sweet Corn	1,800	Radish	2,240	Gluten Wheat	24,320
Goat's Rue	10,880	Sunflower	1,760	Rye	1,720	Wheat	17,280
Rye	9,800	Wheat	1,480	Sweet Peas	1,500	Bur Clover	17,000
Cañaigre	9,160	Carrot	1,240	Artichoke	1,480	Celery	13,680
Ray Grass	6,920	Rye	960	Gluten Wheat	1,480	Rye	12,480
Modiola	6,800	Goat's Rue	760	Wheat	1,160	Goat's Rue	11,800
Bur Clover	5,700	White Melilot	480	Grasses	1,000	Lupin	11,200
Lupin	5,440	Cañaigre	120	White Melilot	440	Cañaigre	9,360
White Melilot	4,920			Goat's Rue	160	Ray Grass	6,920
Celery	4,080					White Melilot	5,840

*In 3 feet. †In 1 foot.

IRRIGATION WITH SALINE WATERS.

It would hardly seem necessary to emphasize specially the danger incurred in irrigation with waters containing unusual amounts of soluble salts; since ordinary common sense clearly indicates the impropriety of increasing the saline contents of soils already charged with them, by the evaporation, year after year, of large masses of saline water. Yet experience has shown that the eagerness to utilize for irrigation whatever water happens to be convenient to good lands, often overcomes both that sense, and the warning given by the published analyses of such waters. Without specifying localities, it may be said that great injury has already been done in California by the disregard of obviously needful caution in this respect. The very slight taste possessed by glauber salt and salsoda does not adequately indicate their presence even when in injurious amounts; so that frequently a chemical test of the waters is the only definite guide. A few general rules, however, will help to enable the irrigator to determine whether or not such examination is called for.

It may be taken for granted that *the waters of all lakes having no regular outflow are unfit for regular irrigation use;* since they must needs contain all the accumulations of salts from the secular evaporation of the waters that flow into them.

The plates annexed exhibit the cultural results of several years' irrigation with the waters of Lake Elsinore, Riverside County, as compared with the growth of orange trees on the same land, but irrigated with artesian water. Lake Elsinore is fed by the San Jacinto River, and in wet years sometimes overflows for a few weeks into Temescal Creek. Thus its saline content varies somewhat, from about 80 to over 100 grains per gallon, of salts containing three-fifths of common salt and one-fifth each of glauber salt and carbonate of soda. The latter, as already stated, tends to form a hardpan in the subsoil, and such hardpan was actually formed where the water was used; and afterwards prevented its proper penetration, so that the trees suffered from dryness of their lower roots, while damaged by the alkali salts near the surface. As mentioned before, experience elsewhere has shown that citrus trees are especially sensitive to common salt.

The investigations made by the Station have, moreover, shown that aside from the frequently saline character of the well and even the artesian waters of the petroleum-bearing region of the State in the coast ranges, the streams of that region, especially the smaller ones, are sometimes too strongly charged with "alkali" (in this case largely the sulfates of soda and magnesia) to be suitable for either irrigation or domestic use. Toward the end of the dry season, even the larger streams

of the southern coast ranges, with their diminished flow, sometimes show an excess of salts. This seems also to be true of the San Jacinto River, which feeds Elsinore Lake.

The waters flowing from the Sierra Madre, south of the Tehachapi range, are throughout of excellent quality for irrigation purposes; as are all those flowing from the Sierra Nevada. The same is true of the artesian waters of the valley of southern California, from Los Angeles east to Redlands, and of all the deeper borings of the Antelope Valley.

In the Great Valley, the artesian waters vary greatly in quality. Those of Kern and Tulare counties are mostly good, sometimes exceptionally so, as in the case of the water-supply of Tulare City. It is only in the shallower borings, near the borders of Tulare Lake, that some waters strongly charged with carbonate of soda or other salts have been found. From Fresno and Merced we have few data as yet; but it seems that north of a line drawn from northeastern Stanislaus via Tracy to Point of Timber, saline waters, sometimes accompanied by some gas, occur at certain levels. But the deep wells bored at Stockton and Sacramento, and northward, have good potable water.

Limits of Saline Contents.—Unfortunately it is not easy to give absolute rules in regard to the exact figures that constitute an excess of salts for irrigation purposes, since not only the composition of the salts, but also the nature of the land to be irrigated, and the frequency and amount of irrigation water required, must be taken into consideration.

Broadly speaking, the extreme limits of mineral content usually assigned for potable waters, viz, 40 grains per gallon, also applies to irrigation waters. Yet it sometimes happens that all or most of the solid content is gypsum and epsom salt; when only a large excess of the latter would constitute a bar to irrigation use. When, on the contrary, a large proportion of the solids consists of carbonate of soda or of common salt, even a smaller proportion of salts than 40 grains might preclude its *regular* use, depending upon the nature of the soil to be irrigated. For in a clay loam, or a heavy adobe, not only do the salts accumulate nearer to the surface, but the subdrainage being slow and imperfect (unless underdrained), it becomes difficult or impossible to wash out the saline accumulations from time to time, as is feasible in sandy lands. In these, moreover, as already stated, the alkali never becomes as concentrated near the surface as in heavier soils. Again, where *hardpan* exists in sandy land, saline irrigation-water soon saturates the soil mass above it with salts.

It has been observed by Means that in the Algerian Sahara region, where the date palm is extensively grown in very sandy land, the trees

FIG. 14. Orange Trees Irrigated with Artesian Water.
Alkali in 4 feet of soil = 2,560 pounds per acre, chiefly sulfate of soda.

FIG. 15. ORANGE TREES IRRIGATED 3 YEARS WITH ALKALI LAKE WATER.
Alkali in 4 feet of soil = 8,920 pounds per acre: Sulfates 4,720, Carbonate 1,680, Chlorid 2,520.

are irrigated regularly with water that contains as much as 213 grains of alkali salts per gallon. The great depths and perviousness of these lands, together with the fact that alkaline salts do not accumulate near the surface in very sandy materials, explain the tolerance, by the palms, of these waters, which are moreover used in great abundance.

During the dry seasons just past saline waters have frequently been used, exceptionally, in order to save trees threatened with death from drought. The Station has even advised that this should be done, with the proviso that *the salts so introduced must be washed into the subdrainage by heavy irrigation,* whenever practicable, even if the same saline water should have to be used for the purpose. For few such waters are sufficiently strong to injure vegetation *until concentrated by evaporation;* as can be seen from the vegetation growing close to the margins of alkaline lakes, with its roots immersed in the water.

The irrigator can determine for himself whether or not his water is of doubtful character, by evaporating a tablespoonful, or more, in a clean silver spoon (avoiding boiling). If the dry residue should form simply a thin, powdery-looking film on the polished metal, he may be assured that the water is all right. If, on the other hand, an obvious saline crust should remain, which will redissolve in water, he should either have an analysis made, or use the water in such a manner as to remove the accumulated salts from time to time by washing them into the subdrainage, if the nature of the soil permits. *A very abundant use of such waters is then preferable to a sparing one;* but the user should *assure himself that it really penetrates,* for otherwise, especially in case much carbonate of soda is present, a dense hardpan may be formed that will allow the trees to perish from drought despite all the water running in the irrigation furrows. A pointed steel probe, three-sixteenths of an inch square, provided with a cross-handle, like a hand auger, ought to be among the tools of every farmer for such tests of his subsoil. No farmer in the arid region can afford to be ignorant of the nature of the substrata within which the bulk of the roots of his crops must vegetate.

RECLAIMABLE AND IRRECLAIMABLE ALKALI LANDS AS DISTINGUISHED BY THEIR NATURAL VEGETATION.

While, as shown above, the adaptation or non-adaptation of particular alkali lands to certain cultures may be determined by sampling the soil and subjecting the leachings to chemical analysis, it is obviously desirable that some other means, if possible available to the farmer himself, should be found to determine the reclaimability and adaptation of such lands for general or special cultures.

The natural plant growth seems to afford such means, both as regards the quality and quantity of the saline ingredients. The most superficial observation shows that certain plants indicate extremely strong alkali lands where they occupy the ground alone; others indicate preëminently the presence of common salt; the presence or absence of still others form definite or probable indications of reclaimability or non-reclaimability. Many such characteristic plants are well known to and readily recognized by the farmers of the alkali districts. "Alkali weeds" are commonly talked about almost everywhere; but the meaning of this term—*i. e.*, the kind of plant designated thereby—varies materially from place to place, according to climate as well as to the quality of the soil. Yet if these characteristic plants could be definitely observed, described, and named, while also ascertaining the amount and kind of alkali they indicate as existing in the land, lists could be formed for the several districts, which would indicate, in a manner intelligible to the farmer himself, the kind and degree of impregnation with which he would have to deal in the reclamation work, thus enabling him to go to work on the basis of his own judgment, without previous reference to this Station.

The carrying-out of such a plan involves, obviously, a very large amount of botanical as well as chemical work, which can not be accomplished within a few seasons; and, in view of the wide differences in the vegetation of the several alkali regions of the State, the same work will have to be repeated to a certain extent in each of these regions. The object to be achieved is, however, of such high practical importance—an importance not remotely appreciated as yet by those not familiar with the enormous extent of otherwise desirable lands in this State that are more or less tainted with alkali—as to deserve the expenditure upon it of a large amount of work as promptly as possible.

The extreme limitation of funds under which the Agricultural College and Experiment Station have been suffering for years, has thus far restricted the scope of these researches very closely, both geographically and otherwise. It is hoped that in the future, a close comparison of the native vegetation with the chemical determination of the quantity

and kind of alkali corresponding to certain plants, or groups of plants, naturally occurring on the land, may enable us to come to a sufficiently close estimate of the nature and capabilities of the latter from the native vegetation alone, or with the aid of test plants purposely grown. But before entering upon this complex problem, it has been thought best to determine, first of all, what lands may for present economic conditions be considered *irreclaimable,* because their improvement would involve an expense out of proportion with present land values. So far as large areas are concerned, this may probably be considered to be the case when tile underdrainage is required in order to wash out the salts; while of course smaller tracts, which interrupt the cultivation of fields, may frequently justify the laying of a few drain lines required to render them cultivable with the rest of the land.

As stated in the report of this Station for 1895-7, the field work of this investigation, both botanical and in the collection of the corresponding soil samples, has been done by Mr. Joseph Burtt Davy, Assistant Botanist to the Station, who also supplies the notes accompanying the same; while the laboratory work for the determination of the amounts and kinds of salts present in the several cases has been carried out by Prof. R. H. Loughridge.

The plants hereinafter mentioned, and figured for the benefit of the great majority of readers who would fail to recognize them from the botanical description alone, are then to be understood as indicating, *whenever they occupy the ground as an abundant and luxuriant growth,* that such land is irreclaimable for ordinary crops, unless underdrained for the purpose of washing out surplus salts. The occurrence merely of scattered, more or less stunted individuals of these plants, while a sure indication of the *presence* of alkali salts, does not necessarily show that the land is irreclaimable.

The plants which may best serve as such indicators in California are the following:

Tussock-grass (*Sporobolus airoides,* Torr.), Fig. 16;

Greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.), Fig. 17;

Dwarf Samphire (*Salicornia subterminalis,* Parish, and other species), Fig. 18;

Bushy Samphire (*Allenrolfea occidentalis* (Wats.) Ktze.), Fig. 19;

Saltwort (*Suaeda Torreyana,* Wats., and *S. suffrutescens,* Wats.), Fig. 20;

Alkali-heath (*Frankenia grandifolia campestris,* Gray), Fig. 21;

Cressa (*Cressa cretica truxillensis,* Choisy), Fig. 22.

TUSSOCK-GRASS* (*Sporobolus airoides*, Torr.); Fig. 16.

The three sets of samples of Tussock-grass soil which have been analyzed show that the total amount of all salts present is in no case less than 49,000 pounds per acre, to a depth of four feet, and that it sometimes reaches the extraordinarily high figure of 499,000 pounds, or more than three per cent. Of these amounts the neutral salts (glauber salt and common salt) are usually in the heaviest proportion (glauber salt, 19,600 to 323,000 pounds per acre; common salt, 3,500 to 172,800); the corrosive salsoda varying from 3,000 to 44,000 pounds. Tussock-grass apparently can not persist in ground which is periodically flooded. It is of special importance because it is an acceptable forage for stock.

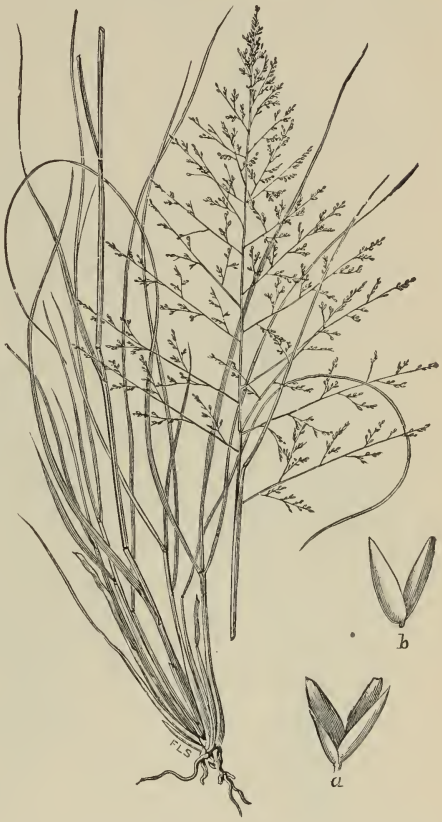

FIG. 16. TUSSOCK-GRASS—*Sporobolus airoides*, TORR. (From Division of Agrostology, U. S. Dept. Agr.)

Tussock-grass is a prevalent alkali-indicator in the hot, arid portions of the interior, from the upper San Joaquin Valley, the Mojave Desert, and southward; also through southern Nevada and Utah as far east as Kansas and Nebraska. In the San Joaquin Valley we have not found it farther north than the Tulare plains, although east of the Sierra it occurs near Reno. Coville observes that in the Death Valley region "it is confined principally to altitudes below 1,000 meters" (3,280 feet). Hillman, however, reports it from near Reno, Nevada, at an altitude which can not be much less than 4,500 feet.

GREASEWOOD† (*Sarcobatus vermiculatus* (Hook.), Torr.); Fig. 17.

Through the courteous coöperation of Prof. F. H. Hillman, Botanist to the Nevada Agricultural Experiment Station at Reno, we have

*So-called because it grows in large clumps or tussocks, which feature unfortunately is not indicated in the illustration.

†This is the true *Greasewood* of the desert region east of the Sierra Nevada, and not either of the plants known under that name in the San Joaquin Valley and in southern California.

obtained three series of samples of Greasewood soil from that vicinity. These samples show that where the Greasewood shrubs are thinly scattered and stunted in growth, the salt content per acre to the depth of three feet is about 2,400 pounds, of which over one half consists of the corrosive carbonates. Where a luxuriant growth occurs the total

FIG. 17. GREASEWOOD (proper)—*Sarcobatus vermiculatus* (Hook.), Torr.

A. Appearance of a branch when not in blossom.
B. Spiny branchlet from the same.
C. Branchlet bearing cones of male flowers.
D. Cone of male flowers, enlarged.
E. Branch bearing fruits.
F. Cluster of fruits, enlarged.
G. Vertical section through a fruit, showing a seed with its curved embryo (enlarged).

salts per acre vary from 38,000 to 58,500 pounds, with 18,700 pounds of salsoda and 920 to 3,680 pounds of common salt; the relative percentage of the injurious salsoda is thus invariably high. The common salt is low and the neutral glauber salt is variable. This plant therefore always indicates the presence of "black alkali."

Greasewood is distinctly a plant of the Great Basin, only reaching California in the adjacent counties of Lassen, Alpine, Mono, and northern Inyo. It is very abundant on the lower levels of Honey Lake Valley, and evidently flourishes best in black alkali.

DWARF SAMPHIRE (*Salicornia subterminalis*, Parish, and other species of the interior); Fig. 18.

The two or three species of Dwarf Samphire which grow in the interior valleys of the State are nowhere very abundant in those portions of the alkali region which we have thus far investigated. Wherever the species do occur, however, they are confined to such very strongly saline soils that they may be considered valuable indicative plants. We have as yet only one full set of samples of Dwarf Samphire soil. This shows the total salt content to amount to 441,880 pounds per acre in a depth of four feet. The neutral glauber salt amounts to 314,000 pounds, almost as much as in Tussock-grass soil; common salt up to 125,640 pounds, while the salsoda varies from 2,200 to 12,000. We may consider this plant as indicative of almost the highest percentage of common salt, glauber salt, and total salts. Like the preceding species, it indicates "white" salts in excessive amounts, and a subsoil too wet for the Australian saltbush.

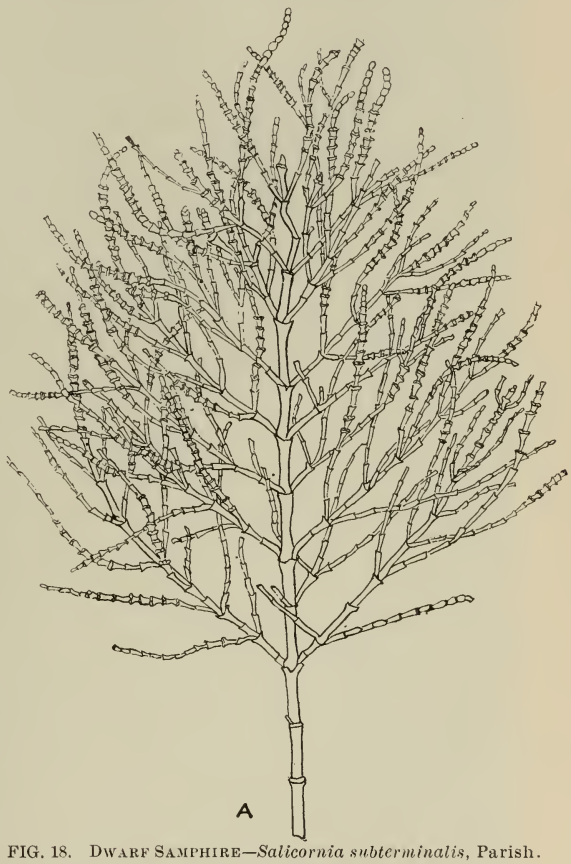

FIG. 18. DWARF SAMPHIRE—*Salicornia subterminalis*, Parish.

BUSHY SAMPHIRE (*Allenrolfea occidentalis* (Wats.) Ktze.); Fig. 19.

This plant is locally called greasewood, but as this name is much more commonly used for *Sarcobatus vermiculatus*, it seems best to call *Allenrolfea* "bushy samphire," as it closely resembles the true samphire (*Salicornia*).

Bushy samphire usually grows in low sinks, in soil which in winter is excessively wet and in summer becomes a "dry bog." Wherever the

FIG. 19. Bushy Samphire—*Allenrolfea occidentalis* (Wats.) Ktze.
[Called "Greasewood" in San Joaquin Valley.]

plant grows luxuriantly the salt content is invariably high, the total salts varying from 327,000 pounds per acre to a depth of three feet, to 494,520 pounds in four feet. The salts consist mainly of glauber and

common salts (a maximum of about 275,000 pounds of each); salsoda varies from 2,360 to 4,800 pounds per acre. The percentage of common salt and total salts is higher than for any other plant investigated, and the glauber salt is almost proportionate. The areas over which this plant grows must therefore be considered as among the most hopeless of alkali lands, for although its salts are "white," submergence during winter precludes the growth of Australian saltbush.

Bushy samphire is a common plant in alkali soils in the upper San Joaquin Valley, around Bakersfield and Delano; a few stunted bushes occur near the margin of Tulare Lake, west of Tulare, but at that point it appears to be dying out. It also occurs on the east slope of Livermore Pass, and in an alkali sink in a pocket of the hills at Byron Springs, Contra Costa County. In the Death Valley region the plant appears to be very abundant, occupying an area considerably more southern than what appears to be the southerly limit of Greasewood (*Sarcobatus*).

FIG. 20. SALTWORT—*Suaeda Torreyana*, Wats.

SALTWORT (*Suaeda Torreyana*, Wats., *S. suffrutescens*, Wats., and perhaps one other species); Fig. 20.

Samples of Saltwort soil from Bakersfield, Kern County, and Byron Springs, Contra Costa County, taken to a depth of one foot and three feet respectively, show that this plant grows luxuriantly in a soil containing 130,000 pounds of salts per acre in the first foot, and with 10,480 pounds of the noxious salsoda and 39,760 pounds of common salt in three feet; while only a sparse growth is found on soils containing only 3,700 pounds of salts in three feet. It thus appears to indicate a lower percentage of salsoda than does Greasewood, but a higher per-

centage than Bushy Samphire. Further investigation is necessary to determine the exact relation of the different salts to the growth of the plant, and as to whether carbonates always occur in large quantity; but enough data have been gathered to show that a luxuriant growth of saltwort indicates a soil practically irreclaimable except at the expense of leaching.

ALKALI-HEATH (*Frankenia grandifolia campestris*, Gray); Fig. 21.

Alkali-heath is perhaps the most widely distributed of any of our California alkali plants. Its perennial, deep-rooting habit of growth, and flexible, somewhat wiry rootstock, which enables it to persist even in cultivated ground, render it a valuable plant as an alkali indicator. The salt content where Alkali-heath grows luxuriantly is invariably high, ranging from 64,000 to 282,000 pounds per acre; salsoda varies from 680 to 19,590 pounds; common salt ranges from 5,000 to 10,000 pounds. Such soils would not be benefited by the application of gypsum, as the salts are already largely in the neutral state. Of useful plants only Saltbushes and Tussock-grass are likely to flourish in such lands.

FIG. 21. ALKALI-HEATH—*Frankenia grandifolia campestris*, A. Gray.

While Alkali-heath is thus one of the most alkali-tolerant plants, it is at the same time capable of growth with a minimum of salts (total salts 3,700 pounds, salsoda 680 pounds). Where only a sparse growth of this plant occurs, therefore, the land should not be condemned until a chemical examination of the soil has been made.

Alkali-heath is found on soils of very varying physical texture and degrees of moisture; while on soils of uniform texture and moisture, but differing in chemical composition, it varies with the varying salt-content.

It has been found that Australian Saltbush (*Atriplex semibaccata*) can be successfully grown on the Colusa County "goose lands," on soil producing a medium crop of Alkali-heath; it remains to be shown

whether it will do equally well on soils producing a dense and luxuriant growth of the same.

Alkali-heath is widely distributed throughout the interior valleys of California. A closely related form is found in salt marshes along the coast, differing from that of the interior principally in its much broader leaves.

CRESSA (*Cressa cretica truxillensis*, Choisy); Fig. 22.

Cressa soils show a low percentage of the noxious salsoda, but comparatively heavy total salts (161,000 to 282,000 pounds per acre). Common salt varies from 5,760 to 20,840 pounds per acre in four feet. The maximum is lower than in the case of Alkali-heath, but Cressa seems to be much more closely restricted to strong alkali than does the former species. Cressa appears to be as widely distributed through the interior valleys of the State as Alkali-heath. It is a cosmopolitan plant, occurring, as its name indicates, on the Ionian Isles, as well as in North Africa, Syria, and in other arid countries of the world.

FIG. 22. CRESSA—*Cressa cretica truxillensis*, Choisy.

RELATIVE TOLERANCE OF THE DIFFERENT SPECIES.

In order to determine the relative nature of the soils characterized by each of the above-named plants, Mr. Davy has prepared the following table, in which the column marked *optimum* shows, as nearly as possible with our present knowledge of the subject, the condition of the soil where each species grows in about equal luxuriance. For Saltwort and Dwarf Samphire we have not yet been able to obtain as thoroughly characteristic soil samples as could be desired, but we hope to be able to do so during the coming season.

It must be understood that the *optimum* indicates the condition under which the plant has been found at its greatest luxuriance—where it is evidently "at home"—; whereas the maximum and minimum have sometimes been obtained where the plants were more or less stunted in growth and sparingly scattered over the ground.

Table Showing Optimum, Maximum, and Minimum of Salts Tolerated by Each of the Several Alkali Plants.

	Pounds per Acre.		
	Optimum.	Maximum.	Minimum.
Total Salts.			
Bushy Samphire	494,520	494,520	135,060
Dwarf Samphires	441,880	441,880	441,880
Alkali-heath	281,960 / 64,300	499,040	3,720
Cressa	281,960	281,960	161,160
Saltworts	130,000	153,020	3,720
Greasewood	58,560	58,560	2,400
Tussock-grass	49,000	499,040	49,000
Carbonates (Salsoda).			
Tussock-grass	23,000	44,460	3,040
Alkali-heath	*19,590 / 680	19,590	680
Greasewood	18,720	18,720	1,280
Dwarf Samphires	12,120	12,120	2,200
Saltworts	10,480	12,120	1,120
Cressa	5,440	5,440	680
Bushy Samphire	4,800	4,800	1,500
Chlorids (Common Salt).			
Bushy Samphire	212,080	275,160	56,800
Dwarf Samphires	125,640	125,640	125,640
Saltworts	39,760	52,900	1,040
Cressa	20,840	20,840	5,760
Alkali-heath	10,180 / 5,760	212,080	1,040
Tussock-grass	6,200	172,800	3,530
Greasewood	3,680	3,680	160
Sulfates (Glauber salt).			
Dwarf Samphires	314,040	314,040	314,040
Bushy Samphire	277,640	277,640	50,080
Cressa	275,520	275,520	134,880
Alkali-heath	275,520 / 34,530	323,200	1,560
Saltworts	44,160	104,040	1,560
Greasewood	36,160	36,160	960
Tussock-grass	19,640	323,200	19,640

*This plant grows with equal luxuriance in soils containing only 680 pounds of carbonates.

In these tables the sequence of the different plants has been arranged so that in each case the species having the highest *optimum* comes at the head of the list. Arranged in this way the tables show that where these plants grow in luxuriance they may be considered indicative of the following conditions:

Total Salts Indicators.—The Samphires, Alkali-heath, and Cressa are all indicative of excessive total salts. Saltwort, Greasewood, and Tussock-grass indicate much lower total salt-content; indeed, the maximum of the two latter plants (Greasewood and Tussock-grass) is so low that the application of gypsum (land-plaster) would *in some cases* (e. g. the Tussock-grass lands near Bakersfield) render the soil adapted to the cultivation of Modiola and Australian Saltbush.

Salsoda Indicators.—It is noticeable that the relative position of the different species in the columns of optimum and maximum is more uniform in the salsoda table than in any other; and whether we arrange the sequence of the plants according to the optimum or to the maximum, the same relative position is maintained. This is in complete accord with what our knowledge of the effect of salsoda on vegetable life would lead us to expect; being by far the most injurious of the alkali salts, the range of tolerance is much smaller, and the limits are much more clearly defined than in the case of the other salts.

Luxuriant growths of Tussock-grass and Greasewood are invariably indicative of high percentages of carbonates, but in such cases the total salt percentage is sometimes so low that the application of gypsum (land-plaster) would render the land fit for the cultivation of Modiola or even Australian Saltbush, as noted above. It must be borne in mind, however, that where Tussock-grass grows but sparsely, the *total* salt-content may reach 499,000 pounds, an amount rendering the land utterly worthless for agricultural purposes unless the surplus salts can be removed.

Alkali-heath can not be taken as an accurate gauge of the salsoda content, as it grows with equal luxuriance on soils containing respectively 680 and 19,590 pounds to the acre, of this salt.

The Samphires and Saltworts are relatively low down in the carbonate table, and may be taken to indicate a comparatively low percentage of "black alkali."

Neutral-Salt Indicators.—The Samphires and Saltworts head the neutral-salt tables, and are reliable indicators of excessively high percentages both of glauber salt and of common salt. Saltwort comes next to Samphire in the common-salt table, but is not quite such a good guide to the glauber salt.

Luxuriant growths of Alkali-heath, Greasewood, and Tussock-grass indicate low percentages of the neutral salts, but these plants will sometimes tolerate (in a sparse state of growth) very high percentages.

CONCLUSIONS.

A review of the above tables and of the more detailed results brings with it the following conclusions:

1. While for the crops in general the maximum tolerance for alkali salts has not yet been definitely found, close approximations are reached with a number, such as the apple, peach, orange, and lemon trees, with respect to carbonate of soda and common salt. In one or two instances alone was the sulfate of soda the apparent cause of distress on the part of a tree.

2. Grapes and olives thus far stand at the head among fruits in their tolerance of each of the alkali salts; oranges grew in a larger amount of carbonate than did the olive, but that salt was chiefly held below the two surface feet. On the other hand, the lemon seems to be the most sensitive to the effects of alkali, especially to common salt, and next to it the orange.

3. The amount tolerated depends largely upon the distribution of the several salts in the vertical soil-column, the injury being most severe in the surface foot, where under the influence of the unfortunate practice of surface-irrigation the feeding rootlets are usually found. It is therefore important that in alkali regions such methods of culture and irrigation should be followed as to encourage deep rooting on the part of crops.

4. The amount tolerated varies with the variety of the same plant, as shown in the grape.

5. The amount of alkali tolerated by the various cultures varies with the nature of the soil. It is lowest in heavy clay soils and fine-grained soils, in which the downward movement of plant roots is restricted; and highest in loam and sandy soils, in which the roots have freedom of penetration.

6. Some plants, such as the saltbush and alfalfa, are quite susceptible to alkali salts when young, but when the roots penetrate deeply, and the ground is heavily covered with the foliage of the plant, they are immune to a very large extent.

7. Lands heavily charged with alkali may often be made productive for certain crops by the application of irrigation water in sufficient amount to leach the salts down to a depth of several (five or six) feet, and by preventing their subsequent rise by proper mulching, or cultivation until the foliage of the plant itself will prevent evaporation of the soil moisture from the surface of the ground. Alfalfa culture has thus been made highly profitable in lands once so strongly charged with alkali as to kill all vegetation.

8. The reclamation of lands charged with carbonate of soda by neutralization with gypsum often renders possible the profitable planting of such crops as withstand large amounts of common salt or of glauber salt.

9. The effects of carbonate of soda are seen in the yellowing of the leaves of the tree caused by its corrosive action on the root-crown, whereby the proper flow of sap and food supply to the leaves is prevented. The effect of common salt is seen in the falling of the leaves from the newer branches, and in the blackening and curling of the leaves of pears.

10. Sulfate of soda (glauber salt) is hurtful only when present in very large amounts, most cultures doing well in more than 10,000 pounds per acre in four feet depth; saltbush, hairy vetch, alfalfa, and sorghum grew well in more than 61,000 pounds.

11. Barley is better adapted to alkali land than is wheat, for it will withstand the effects of twice the amount of carbonate of soda and common salt. Of course, the carbonate may be neutralized with gypsum, and in the absence of much common salt will permit of the growth of excellent crops of wheat; but where the amount of common salt exceeds 5,000 pounds barley should be given the preference over wheat.

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